VARIATION OF IRON LOSS IN TRANSFORMERS WITH SHAPE OF APPLIED E. M. F. WAVE

A. P. STRONG

ARMOUR INSTITUTE OF TECHNOLOGY

1909

537.832
St 8

Illinois Institute
of Technology
Libraries

AT 164
Strong, Arthur Poole
The variation of iron loss
in transformers with shape

11

THE VARIATION OF IRON LOSS IN TRANSFORMERS WITH SHAPE OF APPLIED E.M.F. WAVE

A THESIS

PRESENTED BY

ARTHUR POOLE STRONG

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

ILLINOIS INSTITUTE OF TECHNOLOGY
PAUL V. GALVIN LIBRARY
35 WEST 33RD STREET
CHICAGO, IL 60616

Approved
A. A. Andrews
Prof of E. E.
F. M. Rowe

SUBJECT OF TEST.

Westinghouse 5.K.W. Transformer.

$\frac{110}{220}$ = 1100 Volts. 25. Cycles.

#1017. Serial #123784.

21507

TABLE OF CONTENTS.

Bibliography, - 1.

Description of Appratus, - - - - - - - - - - - - - - - - 2.

Method of proceedure, - - - - - - - - - - - - - - - - - - 4.

Calculation of Results.

Strength of "H" at centre of Coil. - - - - - - - - - - - 5.

Calibration of Oscillograms. - - - - - - - - - - - - - - 6.

Determination of Equation of Curves. - - - - - - - - - - 7.

" " Flux Curves. - - - - - - - 8.

" Hysteresis Loop. - - - - - - - - - - - 9.

Evaluation of " " . - - - - - - - - - - - - 10.

Relation of Form Factor to Modified form of

Steinmetz Constant. - - - - - - - - - - - - - - 11.

Discussion of Experimental Results. - - - - - - - - - - 13.

Conclusions. - 14.

LIST OF PLATES.

Diagram of Connections. - - - - - - - - - - - - - - - Plate 1.

Figure - Section of Coil. - - - - - - - - - - - - - - 2.

Ideal Hysteresis Loop. - - - - - - - - - - - - - - - 3.

Calibration of Curves. - - - - - - - - - - - - - - - 4,5,6,7.

Oscillograms:-

Run #1. - 8 , 10.

" #2. - 15 , 17.

" #3. - 22 , 24.

" #4. - 29 , 31.

" #5. - 36 , 38.

Calibrated Oscillograms.

Run #1. - 9 , 11.

" #2. - 16 , 18.

" #3. - 23 , 25.

" #4. - 30 , 32.

" #5. - 37 , 39.

Data Sheets: -

Run #1. - 18.

" #2. - 19.

" #3. - 26.

" #4. - 37.

" #5. - 40.

CONTINUED.

Efficiency and Regulation: -

Run #1. - 17.
" #2. - 20.
" #3. - 27.
" #4. - 34.
" #5. - 41.

Determination of Hysteresis Loop: -

Run #1. - 14.
" #2. - 21.
" #3. - 28.
" #4. - 35.
" #5. - 42.

Relation of Form Factor to Steinmetz Constant.- 43.

THESIS

Object:- The object of this thesis is a determination of the iron losses in a transformer for various representative wave shapes of applied E.M.F.

The following is a bibliography of the leading articles on the subject:-

(1) Electrical Review, New York. April 26, 1899.

The Effect of Alternating Current Wave Forms on Transformer Losses.

Lousis Duncan, Fred B. Keidel, William L. Hodges, and Edmund Frank.

(2) Elektrolechnische Zeitschrift, July 18, 1907.

Effect of E.M.F. Wave Form on Hysteresis.

W. Elwell Goldsborough.

(3) Engineering News, June 1, 1899.

Transformer Tests.

Carl Fred Holmboe.

(4) Elektrolechnische Zeitschrift, Jan. 17, 1901.

Die Abhängigkeit der Eisenverluste von der Kurvenform.

Dr. Gustav Benischke.

(5) Electrician, May 15-22, 1896.

Experimental Tests On The Influence Of The Shape Of The Applied Potential Difference Wave On The Iron Losses Of Transformers.

Stanley Beeton, C. Percy Taylor, and J. Mark Barr.

(6) Electrician, August 27,1897.

Iron Losses In Transformers And The Higher Harmonics In The Potential Difference Wave.

William Becket Burnie.

(7) Bulletin of The Bureau of Standards, Vol,4,page 4[illegible].

Effect of Wave Form Upon The Iron Losses in Transformers.

Morton G.Lloyd, Assistant Physicist.

In some of the above mentioned articles the authors have secured the separation of the Iron Losses by a change of frequency. In others the resulting hysteresis and eddy current losses are merely noted,no mention being made of the method used in separation.

The method and theory followed in this thesis are both based on fundamental principles at once simple and direct,leaving thereby a minimum source of error.

The different wave shapes were obtained by combining waves from three machines of different frequencies. These were in the ratio of 1 : 2 : 3,giving the first,second, and third harmonics. Photographs were taken of these waves by means of the oscillograph.

The separation of Hysteresis and Eddy Current Losses was obtained in the following simple manner. The low tension winding on the transformer consisted of four 110 volt coils. Two in series,were therefore used as the low tension winding,while the other two,symmetrically located onthe core of the transformer,were used as test coils.

An oscillogram of the wave from the coil of the highest effective value, as read on a voltmeter, was taken. Having found the equation of this wave the equation of the flux wave was obtained by direct integration, according to the fundamental law,

$$e_v = -k\frac{d\Phi}{dt}, \text{ where } k \text{ stands for } \frac{2nf}{10^8}.$$

This curve when plotted with the current wave of excitation will then give points for the determination of the Hysteresis Loop. Thus the hysteresis loss may be obtained. The Eddy Current Loss is then the difference between the Total Watts as measured on the wattmeter and the Hysteresis Loss as found.

DESCRIPTION OF APPARATUS.

The following layout was planned for (a) accuracy (within instrumental errors) (b) convenience of operation and (c) flexibility.

Power was obtained from four alternators, 3-60 cycle and 1-75 cycle connected through shafting and intermediate gear wheels to the same driving unit; thus maintaining constant any desired phase displacement. Due to limited number of coils on the transformer, it was deemed expedient to use 2-110 volt coils in series for the 220 volt side, leaving 2-110 volt coils, symmetrically placed to be used as test coils. Hence it became necessary to arrange the alternators so as to obtain 220 volts from 110 volt-60 cycle machines, at 25 cycles. The deltas of

two of the 60 cycle machines were opened and connected in series, and 175 volts D.C. from a 5 K.W. generator set used as the exciting voltage, instead of 110 volts for which they were designed. These two alternators had their shafts coupled together. To this combination was connected mechanically 1-60 cycle 3-phase alternator with its delta open and connected in series, and 1-75 cycle 3-phase converter through a 1-2 and a 1-3 gear ratio respectively; thus giving three independent frequencies, 25-50-75 cycles. One phase only of the 75 cycle converter was used. All were now so wired that their armatures could all be connected in series or one with any other, thus admitting of four frequency combinations. By shifting the point of contact of the gear wheels with each other, different phase relations were obtained.

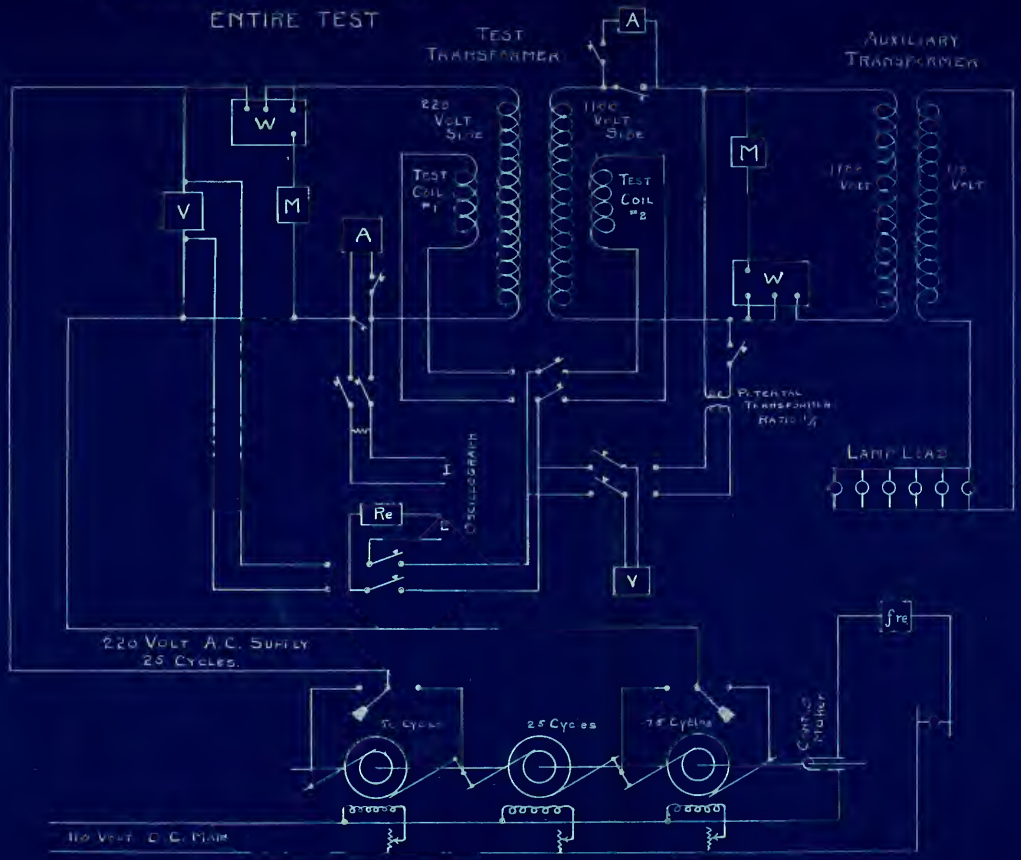
METHOD OF PROCEDURE.

No load readings were taken with supply voltage 220 at the transformer and a constant frequency of 25 cycles. Oscillograms of no load voltage and current, together with an oscillogram of test coil showing a maximum reading, was obtained. On an increase of load the voltage was maintained constant by increasing the excitation of the alternator fields. In the case of two or more alternators in series the voltage of each at no load was obtained and a constant ratio maintained between alternator voltages as the load increased maintaining 220 at the transformer. This precaution was necessary in or-

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

1.

DIAGRAM OF CONNECTIONS
ENTIRE TEST



ARNOUD
INSTITUTE OF TECHNOLOGY
LIBRARY

der to maintain as near as possible the same shape of E.M.F.wave form from zero load to full load.

To avoid the error due to higher harmonics affecting the reading on the frequency meter,a commutator was placed on the shaft of the driving unit and the frequency meter connected in series with series lamp rack through it to 110 volt direct current mains.

CALCULATION OF RESULTS.

Derivation of formula for strength of"H"at centre of coil.

Let m = unit pole at the centre of the coil.

r = distance of an increment dl from the centre of the coil.

b = 1/2 the mean length of the coil.

a = 1/2 the mean width of the coil.

Then force of unit pole at the centre,at a distance r from the centre is

$$f = \frac{m}{r^2}$$

The total force exerted by m on the side RS is

$$F = \int_{r=a}^{r=\sqrt{a^2+b^2}} \frac{m}{r^2}\,dr$$

$$= -\frac{m}{r}\Big|_{r=a}^{r=\sqrt{a^2+b^2}}$$

$$= -\frac{m}{\sqrt{a^2+b^2}} + \frac{m}{a}$$

$$= -m\left[\frac{1}{\sqrt{a^2+b^2}} - \frac{1}{a}\right]$$

a = 9.5
S
T
R
m
b = 15.7
Mean Length Of Coil
Mean Width Of Coil

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

2

Following a similar line of reasoning we obtain for side ST,

$$F = \int_{r=b}^{r=\sqrt{a^2+b^2}} \frac{m}{r^2}\,dr$$

$$= -m\left[\frac{1}{\sqrt{a^2+b^2}} - \frac{1}{b}\right]$$

The total force on the entire coil of one turn and carrying one ampere is then,

$$F_t = -4m\left[\frac{2}{\sqrt{a^2+b^2}} - \frac{1}{b} - \frac{1}{a}\right]$$

But $F_t = Hm$

Therefore

$$H = \frac{F}{m} = -4\left[\frac{2}{\sqrt{a^2+b^2}} - \frac{1}{b} - \frac{1}{a}\right]$$

Substituting now the values of "a" and "b" and multiplying by the number of turns "n",

$n = 102.$ $a = 9.5$cm., $b = 15.0$cm.,

$H = 4.615$ gausses.

CALIBRATION OF OSCILLOGRAMS.

The Oscillograms were copied by means of a pantograph onto coördinate paper. The square root of the mean square was taken of from 40 - 60 ordinates varying with the nature of the curve, at intervals of dx equal to from $\frac{1}{40}$ to $\frac{1}{60}$. This then gave one unit on the Y-axis equal to,

$$\frac{\text{Effective Value by Voltmeter}}{\text{Square Root Mean Square}} \text{ volts.}$$

or, $\frac{\text{Effective Value by Ammeter}}{\text{Square Root Mean Square}}$ amperes,
according to the curve.

DETERMINATION OF EQUATIONS OF CURVES.

It was found upon trial that a strictly mathematical analysis of the curve was the quickest method. The following general form of curve was selected, it being the easiest to integrate for the equation of the flux curve.

$$\begin{matrix} i \\ \text{or} \\ e \end{matrix} = A_1 \sin\theta + A_2 \sin 2\theta + A_3 \sin 3\theta + A_4 \sin 4\theta + A_5 \sin 5\theta \text{---}$$
$$+ A_n \sin n\theta + B_1 \cos\theta + B_2 \cos 2\theta + B_3 \cos 3\theta + B_4 \cos 4\theta$$
$$\text{--------} + B_n \cos n\theta .$$

* The constants A_1 ------ B_1, were found by evaluating the following definite integrals,

$$A_n = \frac{2}{\pi} \int_0^{\pi} e \sin n\theta \, d\theta$$
$$= 2 \times \text{avg.} (e \sin n\theta)_0^{\pi}$$
$$B_n = \frac{2}{\pi} \int_0^{\pi} e \cos n\theta \, d\theta$$
$$= 2 \times \text{avg.} (e \cos n\theta)_0^{\pi}$$

To facilitate the evaluating of the above integrals the curves were all made of a standard length, from zero to zero value on the time axis and this axis divided into 40 parts, instantaneous values of e or i being taken at each division.

* See Steinmetz, Alternating-Current Phenomena (pg. [illegible]).

This made necessary only one set of values of sin $n\theta$ and cos $n\theta$ where θ varies from o - π for each set of indices"n". Values of"n"were 1 - 2 - 3 - 4 - 5 - 6.

Let A_n = value thus obtained.

a = ratio of enlargement from Curve of Calibration to Curve of Equation.

y = volts or amperes per division of Calibration Curve.

The physical length of Y divisions for both curves is the same.

z = volts or amperes per Y division of curve of equation.

Then

$$z = \frac{Y}{a}$$

Therefore A_n of the final equation of E.M.F. curve

$$= \frac{Y}{a} A_n$$

In the determination of the equation of curves having a prominent second harmonic (Runs#4 and #5) the determination had to be made for both positive and negative lobes, since the frequency of both was different, each lobe however, representing radians.

DETERMINATION OF EQUATIONS OF FLUX CURVES.

Let $e = A_1 \sin \theta + A_2 \sin 2\theta + A_3 \sin 3\theta \text{ ----} + A_n \sin n\theta$

$+ B_1 \cos \theta + B_2 \cos 2\theta + B_3 \cos 3\theta \text{ ----} + B_n \cos n\theta.$

be the equation of the E.M.F. wave from the test coil for the no load condition of the transformer for the

Run under consideration.

Then the equation of the flux curve is

$$\phi = \int (A_1 \sin\theta + A_2 \sin 2\theta + A_3 \sin 3\theta \text{ -----} + A_n \sin n\theta$$
$$+ B_1 \cos\theta + B_2 \cos 2\theta + B_3 \cos 3\theta \text{ -----} + B_n \cos n\theta) \, d\theta .$$

$$\phi = - A_1 \cos\theta - \frac{A_2}{2}\cos 2\theta - \frac{A_3}{3}\cos 3\theta \text{ ----} - \frac{A_n}{n}\cos n\theta$$

$$+ B_1 \sin\theta + \frac{B_2}{2}\sin 2\theta + \frac{B_3}{3}\sin 3\theta \text{ ----} + \frac{B_n}{n}\sin n\theta + C$$

The constant of integration"C",operates to raise or lower each ordinate of the curve by the same amount. The Flux Curve repeats itself for odd harmonics every half cycle,and for both odd and even,every cycle. Therefore the constant"C"is of such a value that will cause the positive and negative values to assume the same numerical value,at"o"and"$\frac{\pi}{2}$". For the flux equation for E.M.F.containing a prominent second harmonic, the equation of each lobe was obtained separately. Hence a constant of integration for each lobe such that it will fulfill the last named condition is necessary.

DETERMINATION OF HYSTERESIS LOOP.

The Hysteresis Loop is nothing more than a curve expressing the relation between the flux and the current,at each instant during an entire cycle. Therefore the flux curve plotted in conjunction with the current curve of excitation will give this relation. The E.M.F. due to eddy currents is so small that it may be neglected.

EVALUATION OF HYSTERESIS LOOP.

Let a = gausses per inch on "H".

b = lines per sq.inch per inch on "B".

w = watts per cycle.

V = volume iron in cubic inches.

A = area of loop in square inches.

Then

* $$w = \frac{abVA}{4\ 10^7}$$

If f = cycles per second,

Then

$$w = \frac{abVAf}{4\ 10^7} \text{ watts.}$$

In the curves plotted:-

One ampere equals 2 cm.

Hence One ampere is equivalent to 4.615 gausses

Therefore,

One inch is equivalent to

$$a = \frac{2.54}{2} \times 4.615 \text{ gausses.}$$

$$= 5.86 \text{ gausses.}$$

Also, Two cm. are equivalent to 10,000 lines.

Therefore,

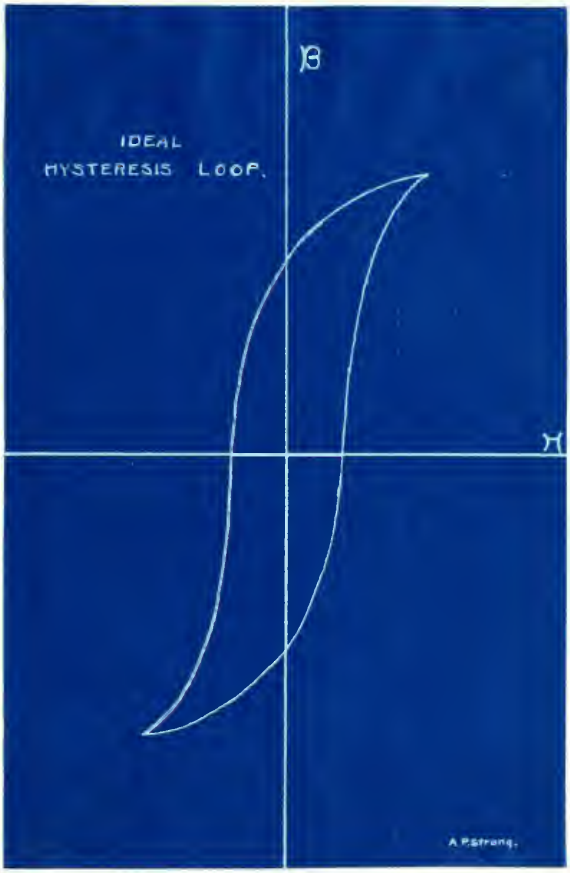
One inch is equivalent to

$$b = \frac{2.54}{2} \times 10{,}000 \text{ lines.}$$

$$= 12{,}700 \text{ lines.}$$

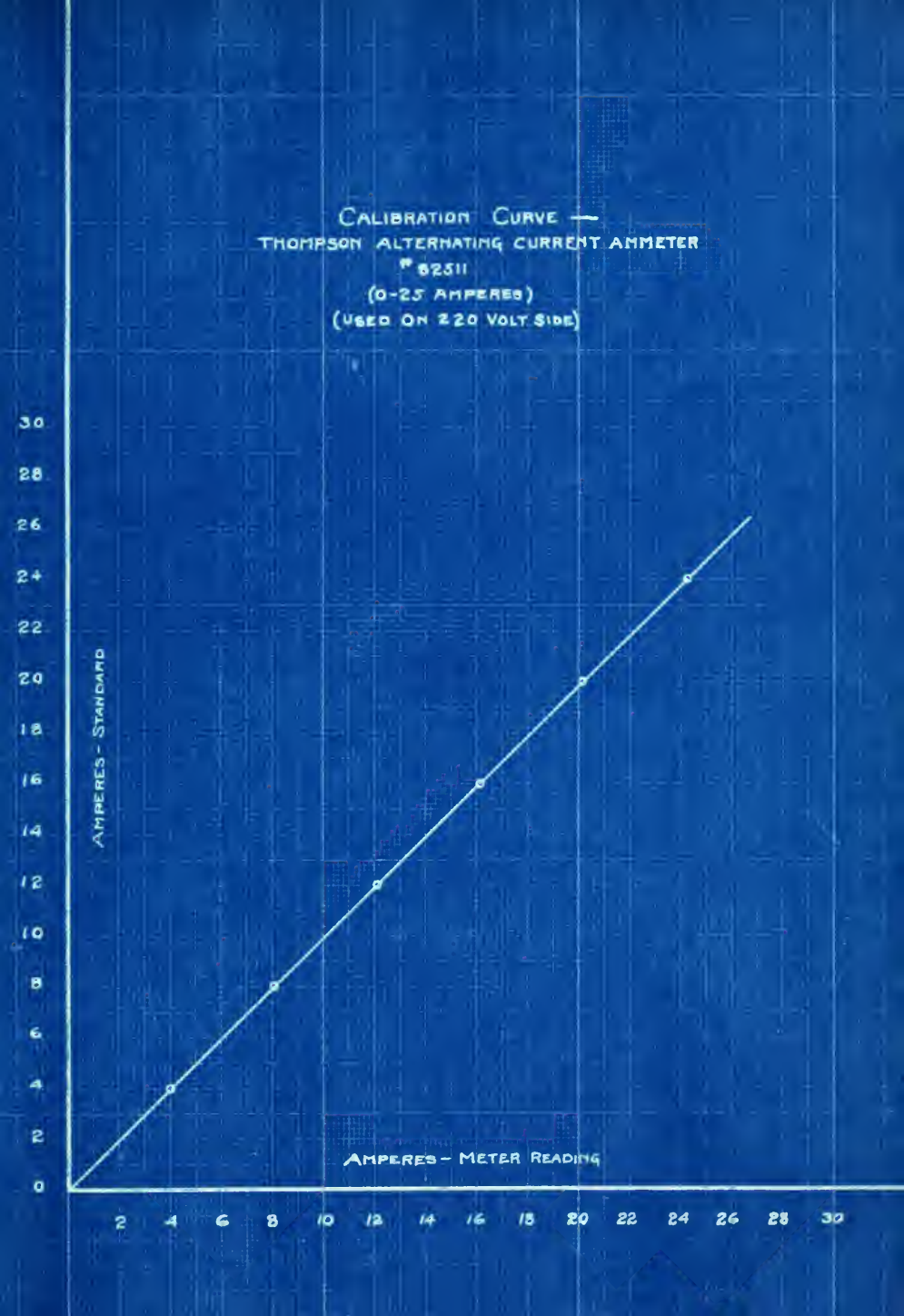
From data obtained from the makers of the transformer, 194 pounds of iron were used in the core of a density .277 pounds per cubic inch.

* Franklin & Esty, Elements of Electrical Engineering Direct Currents page 379.


IDEAL
HYSTERESIS LOOP.
B
H
A.P.Strong.

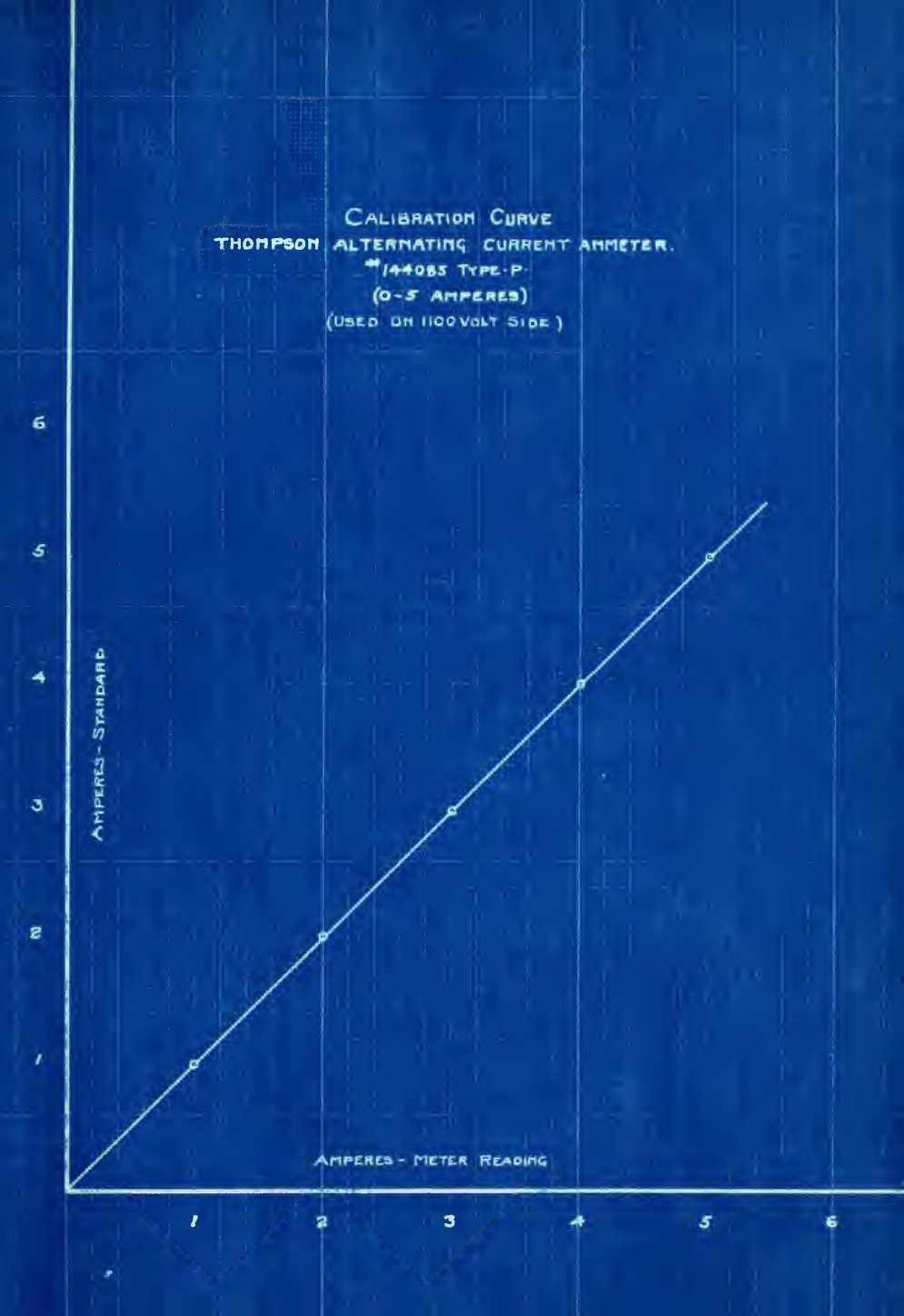
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

3.


CALIBRATION CURVE —
THOMPSON ALTERNATING CURRENT AMMETER
82511
(0-25 AMPERES)
(USED ON 220 VOLT SIDE)
AMPERES - STANDARD
AMPERES - METER READING
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

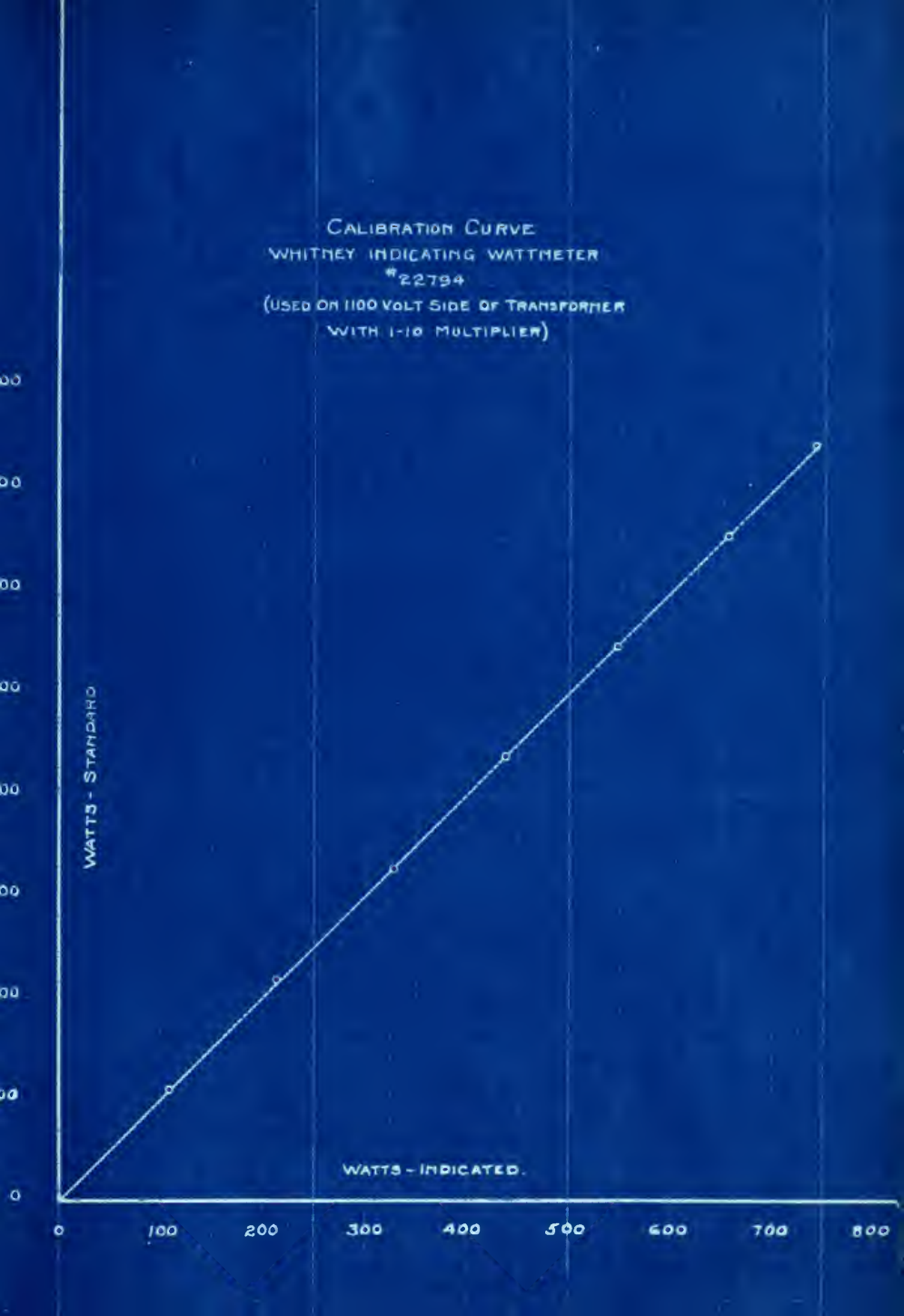
GROUP
INSTITUTE OF TECHNOLOGY
KANPUR

4.


CALIBRATION CURVE
THOMPSON ALTERNATING CURRENT AMMETER.
#144083 TYPE-P
(0-5 AMPERES)
(USED ON 1100 VOLT SIDE)
AMPERES - STANDARD
AMPERES - METER READING
1
2
3
4
5
6

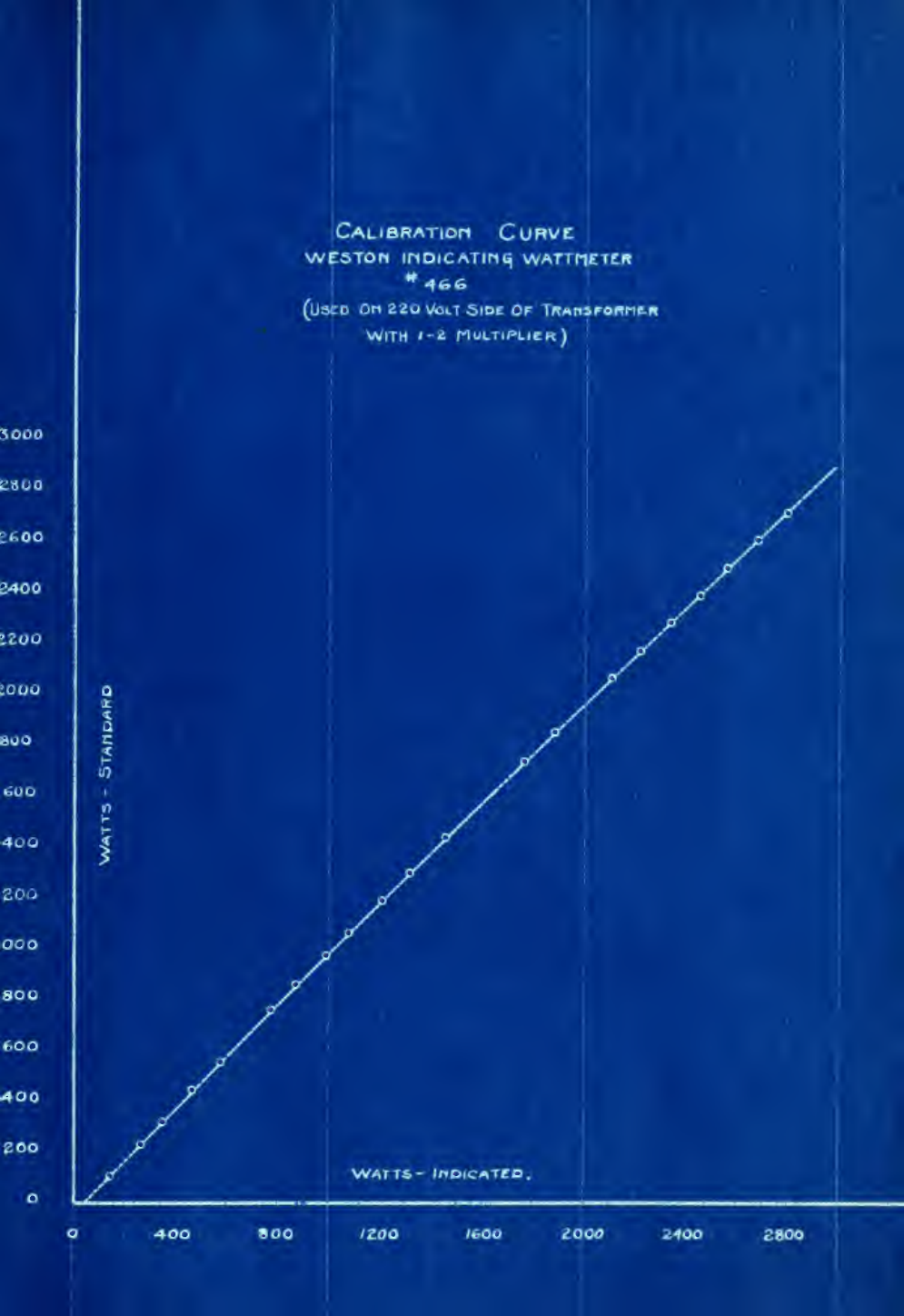
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

5.


CALIBRATION CURVE
WHITNEY INDICATING WATTMETER
#22794
(USED ON 1100 VOLT SIDE OF TRANSFORMER
WITH 1-10 MULTIPLIER)
WATTS - STANDARD
WATTS - INDICATED.
0
100
200
300
400
500
600
700
800

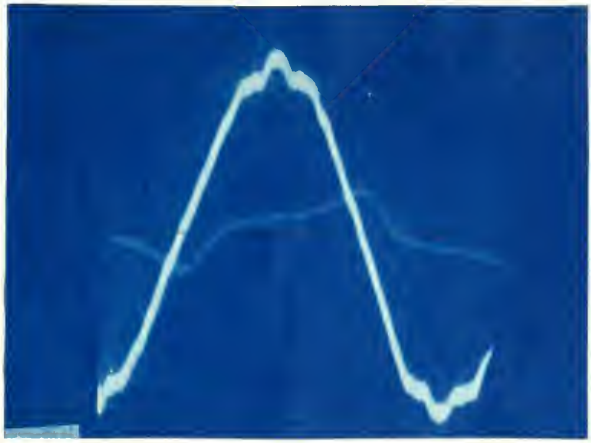
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

6


CALIBRATION CURVE
WESTON INDICATING WATTMETER
466
(USED ON 220 VOLT SIDE OF TRANSFORMER
WITH 1-2 MULTIPLIER)
WATTS - STANDARD
WATTS - INDICATED.
3000
2800
2600
2400
2200
2000
800
600
400
200
000
800
600
400
200
0
0
400
800
1200
1600
2000
2400
2800

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

7



RUN #1.

First Harmonic.

ARCHIVE
INSTITUTE OF TECHNOLOGY
MADRAS

8.

Run No 1

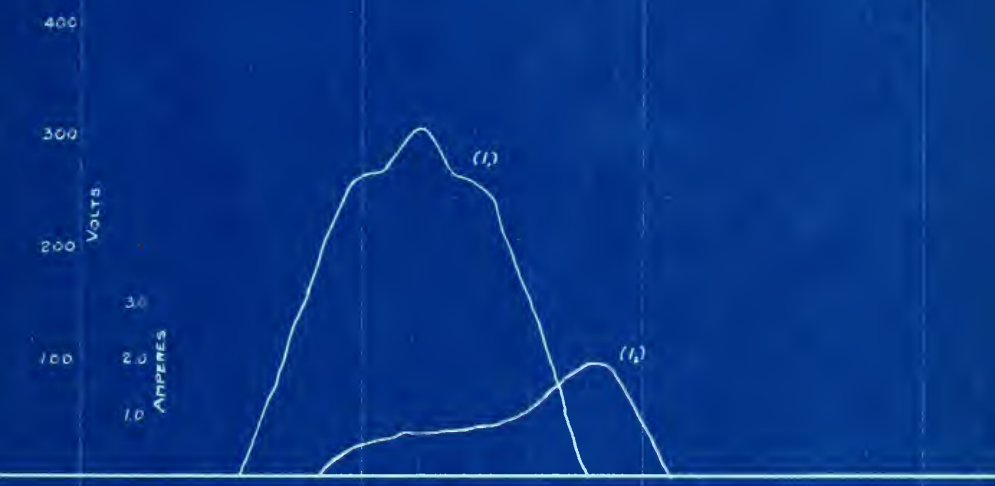
FIRST HARMONIC SUPPLIED

EXCITING E.M.F. AND CURRENT

CURVES

(I_1) EFFECTIVE E.M.F. 220 VOLTS

(I_2) " I 1.1 AMPERES

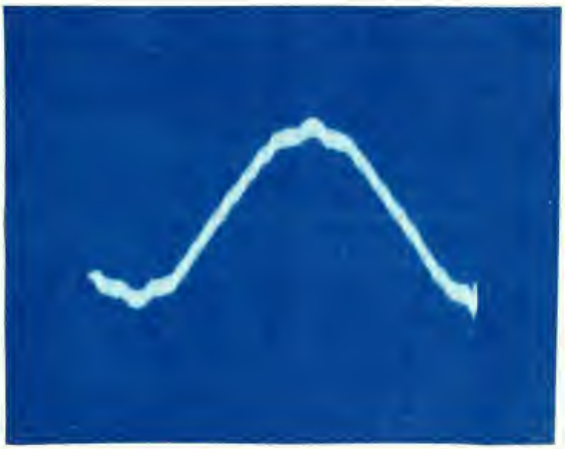


EQUATIONS OF CURVES

E.M.F.	CURRENT.
$A_1 = +12.67$	$A_1 = +.486$
$A_2 = +4.89$	$A_2 = +.227$
$A_3 = -11.12$	$A_3 = +.475$
$A_4 = +13.36$	$A_4 = -.042$
$A_5 = -2.76$	$A_5 = +.012$
$A_6 = -1.51$	$A_6 = +.021$
$B_1 = +118.70$	$B_1 = +.342$
$B_2 = +23.55$	$B_2 = +.262$
$B_3 = +3.70$	$B_3 = +.193$
$B_4 = -30.10$	$B_4 = -.358$
$B_5 = +2.83$	$B_5 = +.159$
$B_6 = -12.18$	$B_6 = -.106$

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

9.



RUN #1.

No Load Condition of Flux.

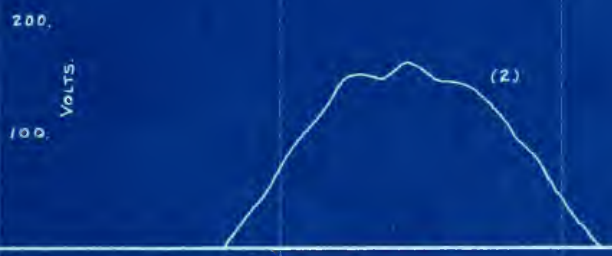
E.M.F. Test Coil #2.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

10

Run No 1.

CURVE OF INDUCED E.M.F. IN
TEST COIL NO. 2.
NO LOAD
(2) EFFECTIVE E.M.F. 111.0 VOLTS.



EQUATION OF CURVE

$A_1 = +2.113$	$B_1 = -72.2$
$A_2 = -5.500$	$B_2 = -16.50$
$A_3 = -4.230$	$B_3 = -7.08$
$A_4 = -1.010$	$B_4 = -15.53$
$A_5 = -4.210$	$B_5 = -1.22$
$A_6 = +21.000$	$B_6 = -2.30$

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

11

Run Number 1

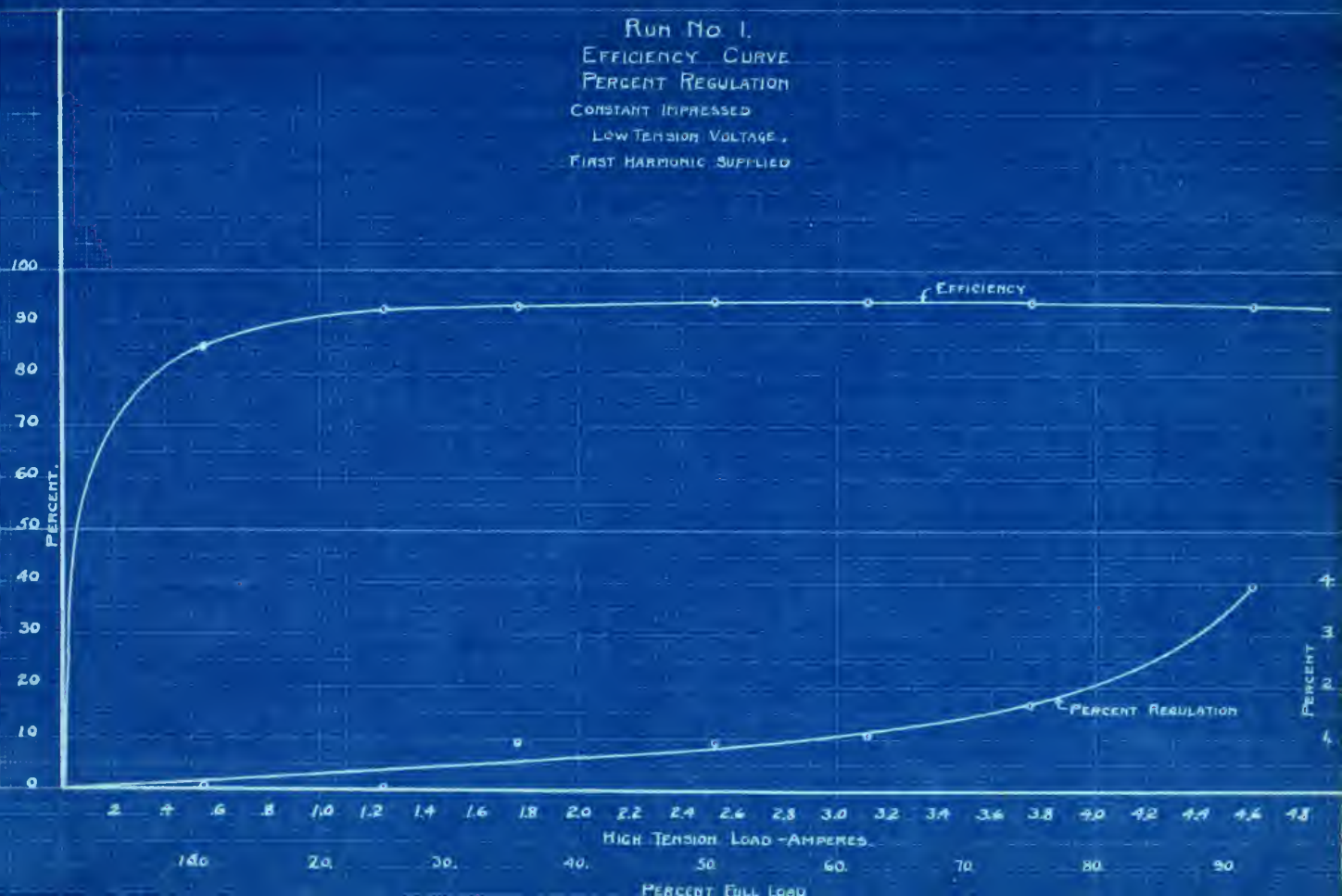
Harmonics Supplied - First

Fundamental Frequency 25 Cycles Per Second.

Reading Number	1	2	3	4	5	6	7	8	9
Test Coil #1									
Number E.M.F. Curve									
Induced Voltage	111.0	111.1	111.3	111.0	110.4	110.0	110.0	108.5	107.5
Corrected Voltage	111.0	111.1	111.3	111.0	110.4	110.0	110.0	108.5	107.5
Test Coil #2									
Induced Voltage	111.0	111.2	111.3	111.2	110.7	110.3	110.1	108.8	107.8
Corrected Voltage	111.0	111.2	111.3	111.2	110.7	110.3	110.1	108.8	107.8
Number E.M.F. Curve	2								
Supply									
Voltage	220	220	220	220	220	220	220	220	220
Corrected Voltage	220	220	220	220	220	220	220	220	220
Number E.M.F. Curve	1.								
Current	1.1	4.0	7.04	9.8	13.4	16.2	19.5	23.0	24.5
Corrected Value	1.1	4.0	6.90	9.7	13.20	16.0	19.25	22.75	24.3
No. Current Curve	I_2								
Watts - Input	140	760	1530	2100	2960	3640	4400	5000	5400
Corrected Value	54	700	1486	2070	2920	3.8[illegible]	4310	4690	5320
Load									
Voltage	1100.	1100.	1100.	1090.	1090.	1088.	1082.	1067	1058
Corrected Value	1100	1100	1100	1090	1090	1088	1082	1067	1058
Current	0	.55	1.25	1.77	2.53	3.12	3.75	4.30	4.67
Corrected Value	0	.55	1.25	1.77	2.53	3.12	3.75	4.30	4.67
Watts - Load	0	600	1372	1950	2770	3400	4090	4430	5000
Corrected Value	0	600	1372	1930	2745	3360	4050	4390	4950
Percent Efficiency	0	85.6	92.5	93.2	94.0	94.1	94.0	93.6	93.0
" Regulation	0	0	0	.918	.92	1.102	1.602	2.7	4.5
Hysteresis Loss	39.5								
Eddy Current Loss	14.5								

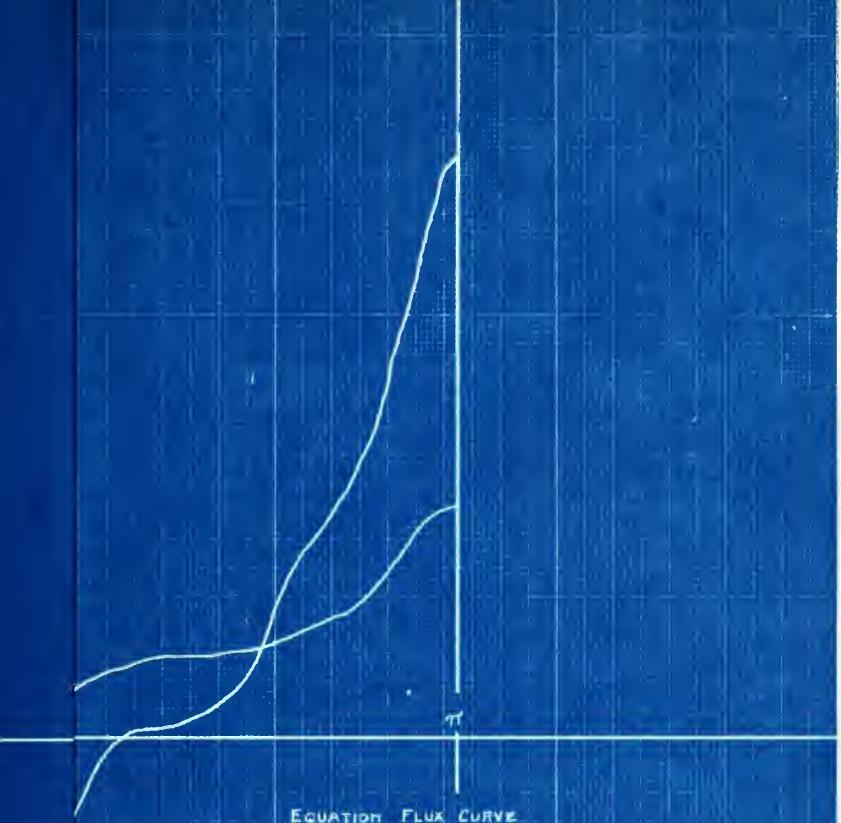
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

12


Run No 1.
Efficiency Curve
Percent Regulation
Constant Impressed
Low Tension Voltage,
First Harmonic Supplied
Efficiency
Percent Regulation
Percent.
Percent
100
90
80
70
60
50
40
30
20
10
0
4
3
2
1
.2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8
High Tension Load - Amperes.
10.0 20. 30. 40. 50 60. 70 80 90
Percent Full Load

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

13.



EQUATION FLUX CURVE

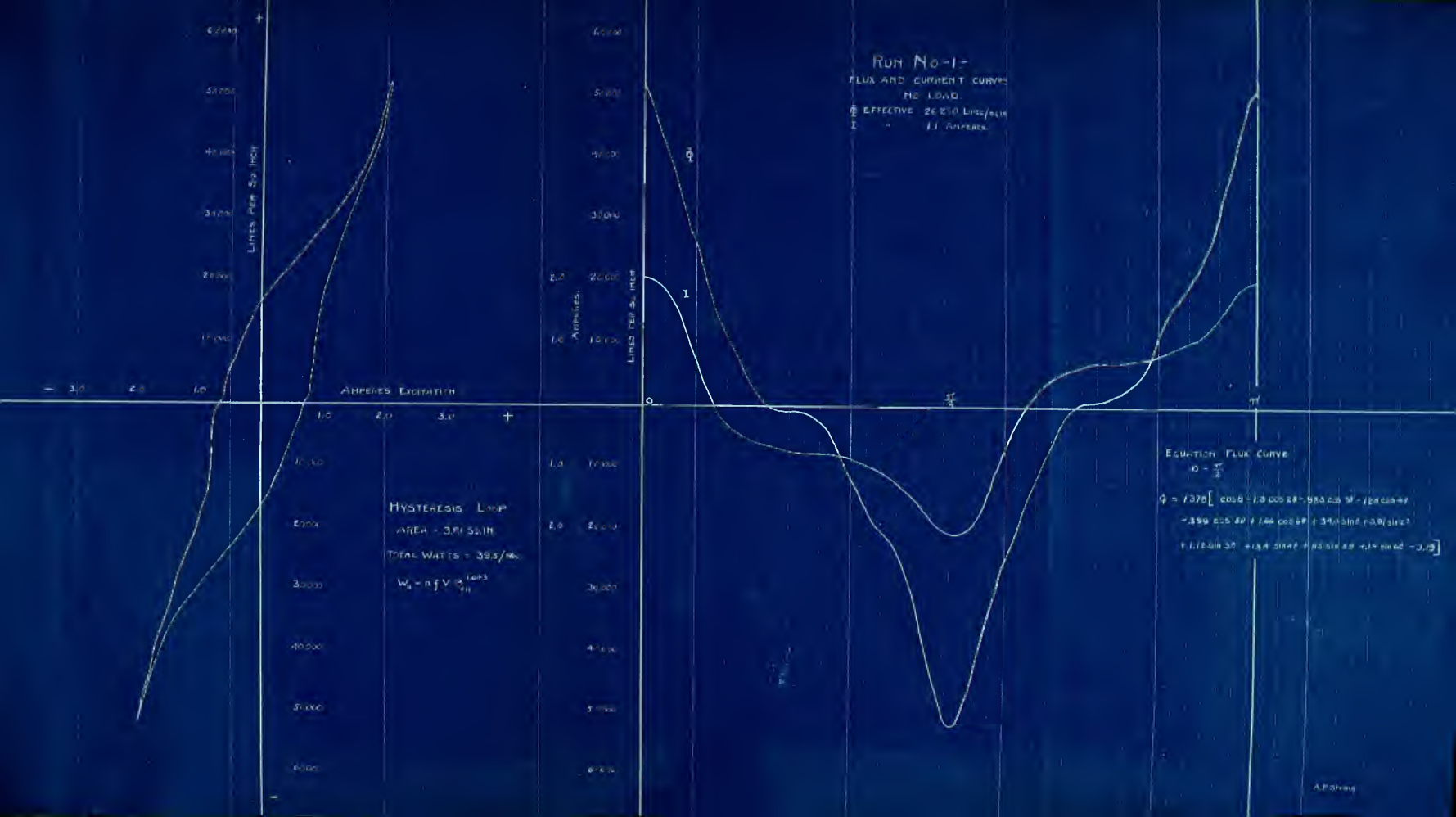
$0 - \frac{\pi}{2}$

$$\phi = 1378\Big[\cos\theta - 1.3\cos 2\theta - .983\cos 3\theta - .120\cos 4\theta$$
$$-.399\cos 5\theta + 1.66\cos 6\theta + 34.0\sin\theta + 3.91\sin 2\theta$$
$$+1.12\sin 3\theta + 1.24\sin 4\theta + .115\sin 5\theta + .18\sin 6\theta - 3.19\Big]$$

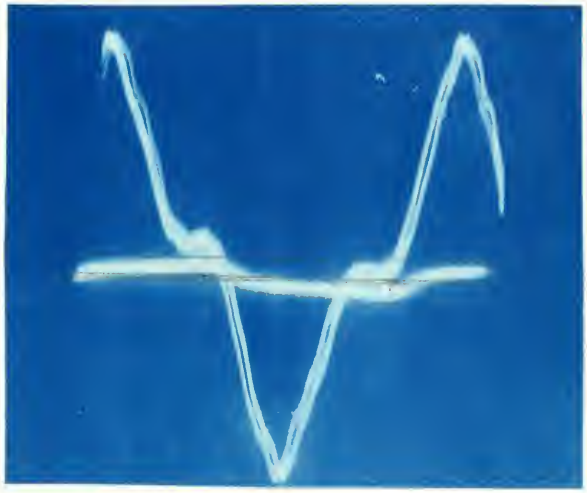
A. P. Strong

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

13.


Run No-1-
Flux and Current Curves
No Load
Φ Effective 26,250 Lines/sq in
I " 1.1 Amperes
Φ
I
Lines Per Sq. Inch
Amperes
Amperes Excitation
Hysteresis Loop
Area = 3.81 Sq. In
Total Watts = 39.5/sec
Equation Flux Curve
θ = π/2
A.P. Strong

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

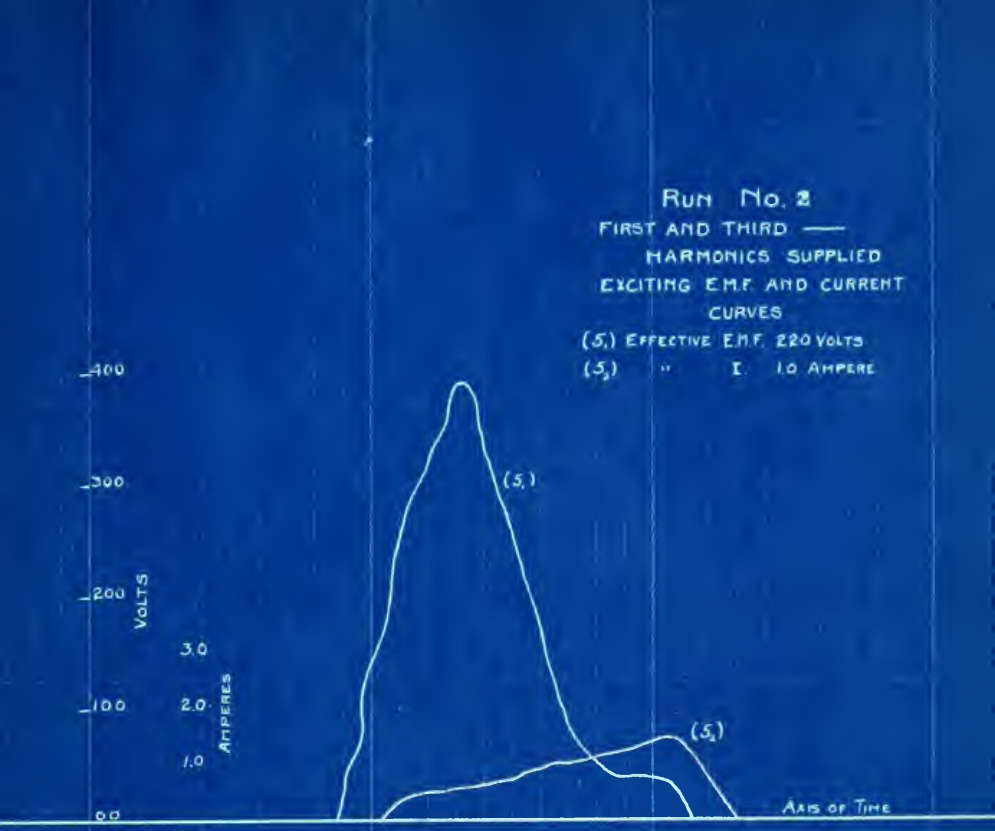


RUN #2.

First and Third Harmonic

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

15.



- Equations of Curves. -

E.M.F.

$A_1 = +107.8$
$A_2 = +30.7$
$A_3 = -11.02$
$A_4 = +37.20$
$A_5 = -1.60$
$A_6 = +19.60$
$B_1 = -98.50$
$B_2 = -23.40$
$B_3 = +93.20$
$B_4 = -19.96$
$B_5 = +3.18$
$B_6 = -13.68$

Current

$A_1 = -.268$
$A_2 = +.045$
$A_3 = +.275$
$A_4 = +.007$
$A_5 = +.057$
$A_6 = -.089$
$B_1 = +.573$
$B_2 = +.264$
$B_3 = -.147$
$B_4 = -.146$
$B_5 = -.115$
$B_6 = -.084$

A.P. Strong

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

16

RUN #3.

No Load Condition Of Flux.

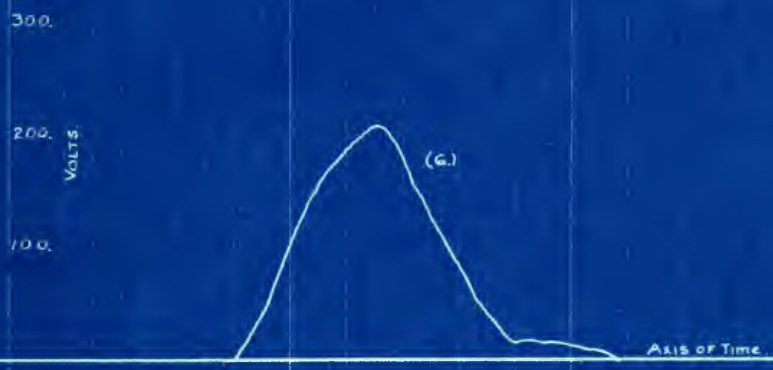
E.M.F. Test Coil #3.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

17

Run No. 2.

CURVE OF INDUCED E.M.F. IN
TEST COIL NO. 2
— NO LOAD —
(6.) EFFECTIVE E.M.F. 111.8 VOLTS



— EQUATION OF CURVE —

$A_1 = -\ 54.00$	$B_1 = +\ 43.50$
$A_2 = -\ 14.03$	$B_2 = -\ 14.03$
$A_3 = +\ 4.71$	$B_3 = -\ 49.90$
$A_4 = -\ 14.50$	$B_4 = -\ 13.68$
$A_5 = -\ .56$	$B_5 = -\ 2.97$
$A_6 = +\ 4.17$	$B_6 = -\ 4.82$

A. F. Strang

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

18

Run Number 2

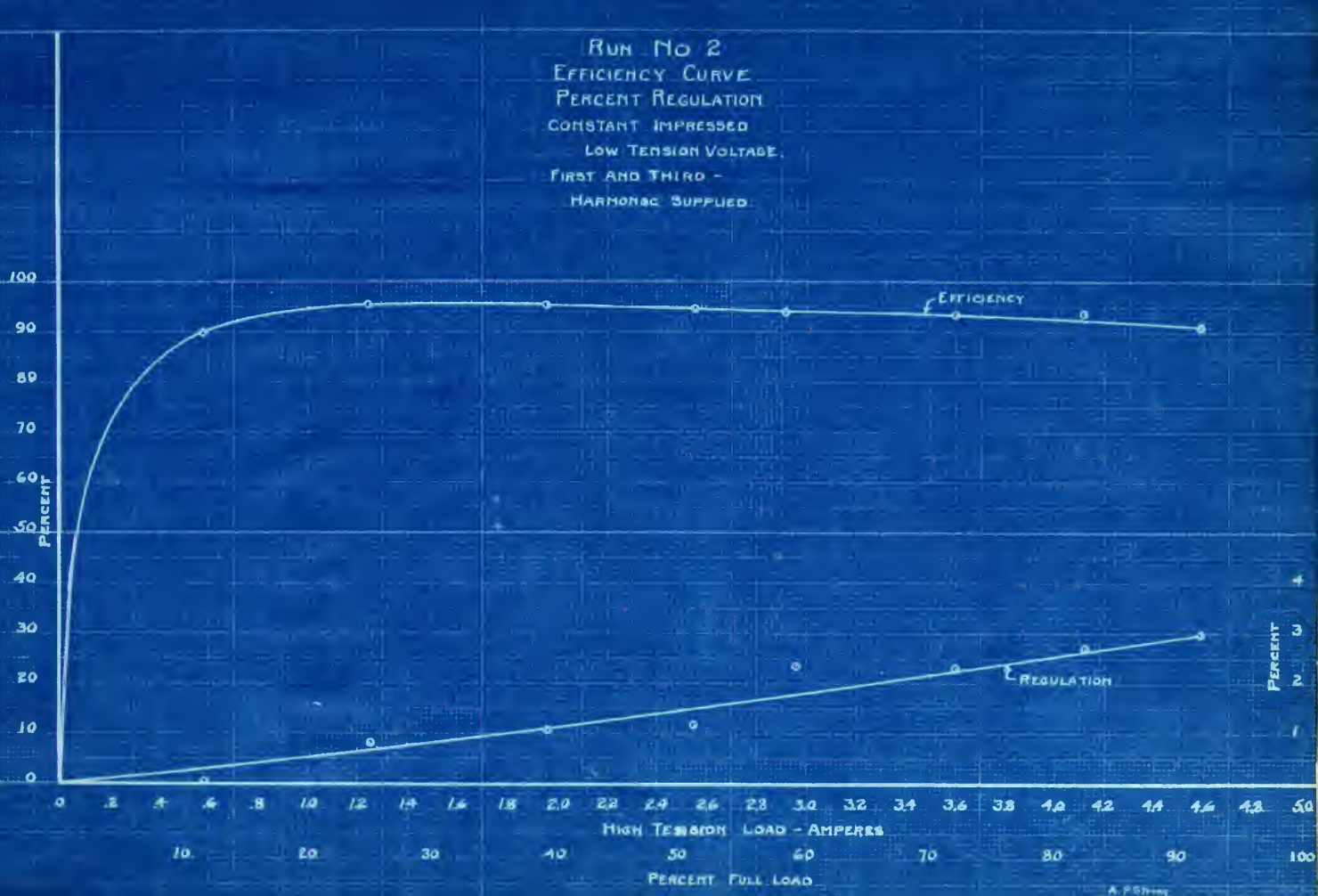
Harmonics Supplied - First Third

Fundamental Frequency 25 Cycles Per Second

Reading Number	1	2	3	4	5	6	7	8	9
Test Coil #1									
Number E.M.F. Curve									
Induced Voltage	111.6	111.3	111.2	110.9	111.1	110.0	110.0	110.0	109.3
Corrected Voltage	111.6	111.3	111.2	110.9	111.1	110.0	110.0	110.0	109.3
Test Coil #2									
Induced Voltage	111.8	111.4	111.3	111.0	111.4	110.1	110.0	110.2	109.7
Corrected Voltage	111.8	111.4	111.3	111.0	111.4	110.1	110.0	110.2	109.7
Number E.M.F. Curve	6								
Supply									
Voltage	220	220	220	220	220	220	220	220	220
Corrected Value	220	220	220	220	220	220	220	220	220
Number E.M.F. Curve	5_1								
Current	1.0	3.7	6.9	10.4	13.5	15.3	18.7	21.7	24.8
Corrected Value	1.0	3.65	6.80	10.25	13.30	15.10	18.45	21.4	24.5
No. Current Curve	5_2								
Watts - Input	180	760	1480	2260	2980	3365	4250	4660	5400
Corrected Value	90	700	1440	2230	2940	3330	4166	4740	5440
Load									
Voltage	1112	1112.	1103.	1100.	1099	1086	1087	1083	1080
Corrected Value	1112	1112	1103	1100	1099	1086	1087	1083	1080
Current	0	.58	1.25	1.96	2.55	2.92	3.59	4.12	4.59
Corrected Value	0	.58	1.25	1.96	2.55	2.92	3.59	4.12	4.59
Watts - Load		630	1380	2150	2800	3150	3950	4500	5000
Corrected Value	0	630	1315	2130	2780	3130	3900	4460	4950
Percent Efficiency	0	90.0	95.5	95.5	94.5	94.0	93.5	93.9	91.0
" Regulation	0	0	.815	1.090	1.182	2.895	2.30	2.6	2.96
Hysteresis Loss	85.5								
Eddy Current Loss	4.5								

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

19


Run No 2
Efficiency Curve
Percent Regulation
Constant Impressed
Low Tension Voltage.
First and Third -
Harmonic Supplied
Efficiency
Regulation
Percent
Percent
High Tension Load - Amperes
Percent Full Load
A. P. Stone

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

20

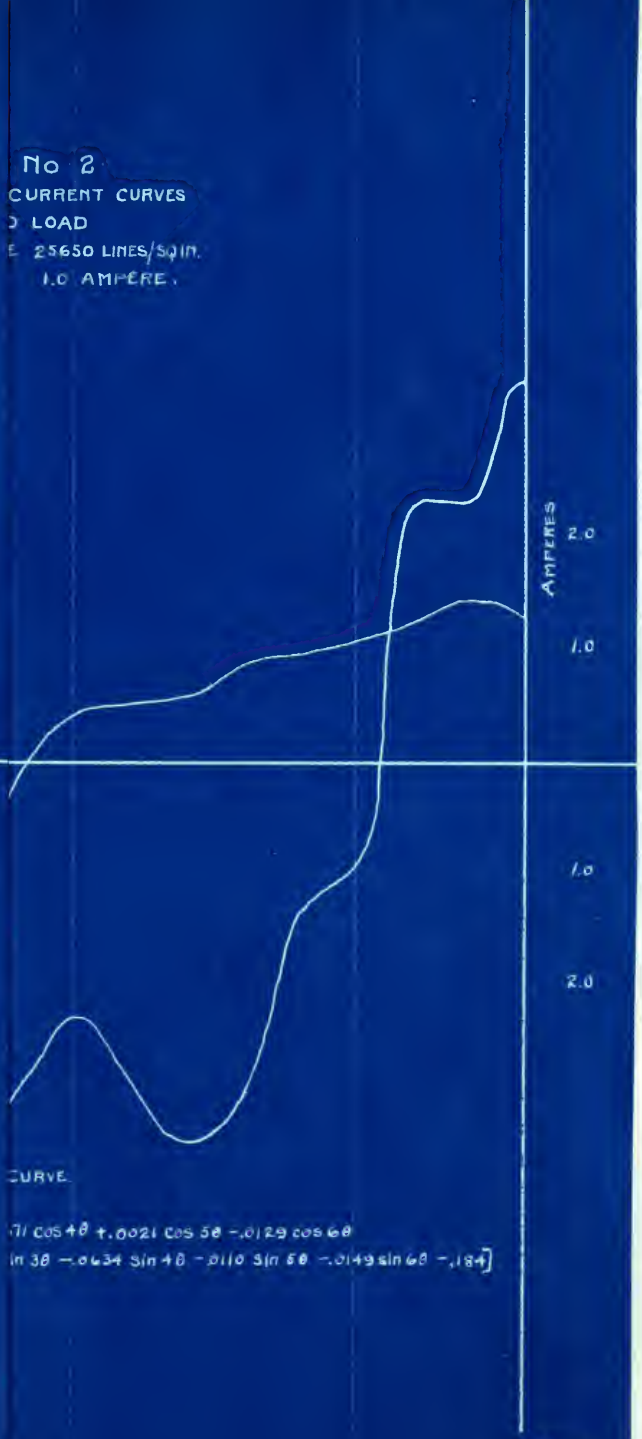
No 2

CURRENT CURVES

) LOAD

E 25650 LINES/SQ.IN.

1.0 AMPERE.



CURVE

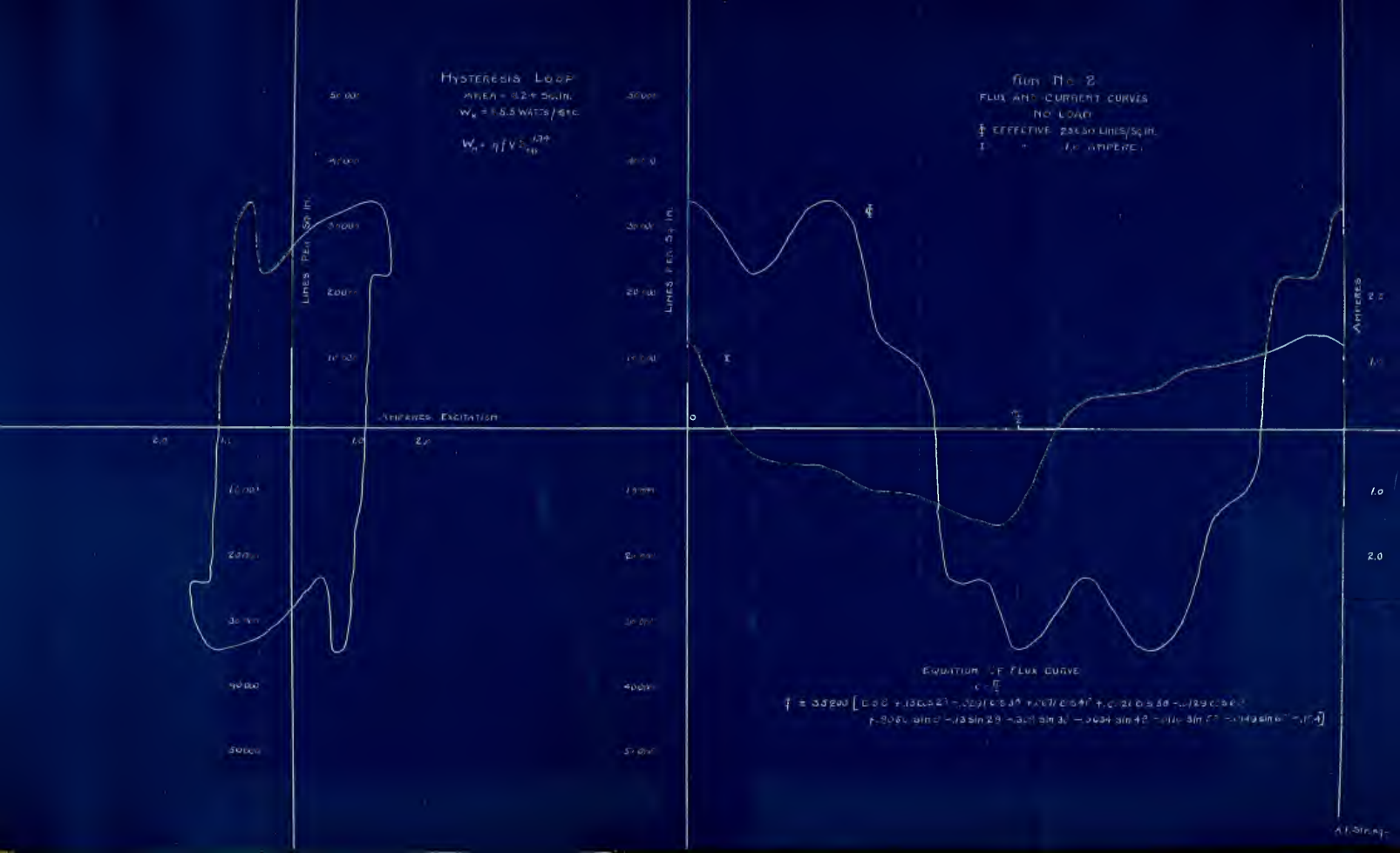
71 cos 4θ +.0021 cos 5θ −.0129 cos 6θ

in 3θ −.0634 sin 4θ −.0110 sin 5θ −.0149 sin 6θ −.184]

A.P.Strong.

ARCHIVE
INSTITUTE OF TECHNOLOGY
LIBRARY

2c


Hysteresis Loop
Area = 8.24 Sq.in.
$W_h = 1.65$ Watts/sec.
$W_h = \eta f V B_m^{1.64}$
Lines per Sq. in.
Amperes. Excitation
Run No. 2
Flux and Current Curves
No Load
Φ Effective 23630 Lines/Sq.in.
I " 1.0 Ampere.
Amperes
Equation of Flux Curve
$\Phi = 33200 [0.00 + .136 \sin \theta + .029 \sin 2\theta + .067 \sin 3\theta + .021 \sin 4\theta + .129 \sin 5\theta$
$+ .006 \sin 6\theta + .135 \sin 7\theta + .021 \sin 8\theta + .034 \sin 9\theta + .010 \sin 10\theta + .014 \sin 11\theta + .014]$

ARNOUD
INSTITUTE OF TECHNOLOGY
KERAPATI

RUN #7.

First and Third Harmonic.

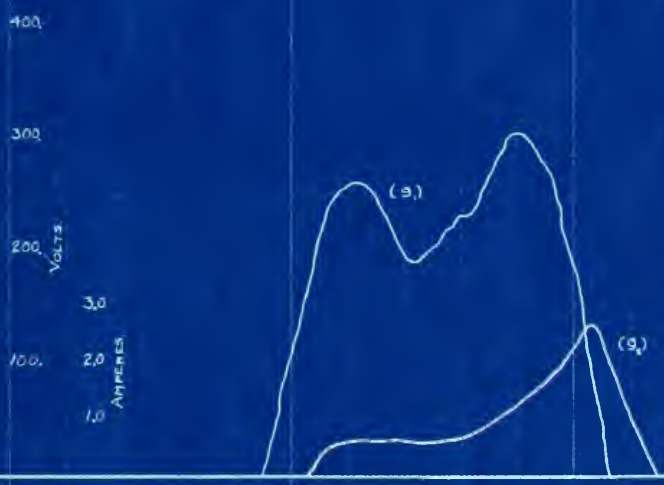
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

22.

Run No-3-

FIRST AND THIRD HARMONICS
SUPPLIED
EXCITING E.M.F. AND CURRENT
CURVES

(9) EFFECTIVE E.M.F. 220 VOLTS.
(9_1) " I 1.1 AMPERES.



EQUATIONS OF CURVES.

E.M.F.	Current
$A_1 = +1.93$	$A_1 = -.785$
$A_2 = +2.86$	$A_2 = +.070$
$A_3 = +55.60$	$A_3 = +.715$
$A_4 = -2.80$	$A_4 = +.136$
$A_5 = -8.73$	$A_5 = +.243$
$A_6 = -43.80$	$A_6 = -.040$
$B_1 = +75.80$	$B_1 = +.560$
$B_2 = -7.94$	$B_2 = +.339$
$B_3 = +9.39$	$B_3 = -.400$
$B_4 = -78.60$	$B_4 = -.442$
$B_5 = +.67$	$B_5 = -.303$
$B_6 = -18.50$	$B_6 = -.266$

A.P.Strong

ARNOUD
INSTITUTE OF TECHNOLOGY
BARNAUL

23

RUN #3.

No Load Condition Of Flux.

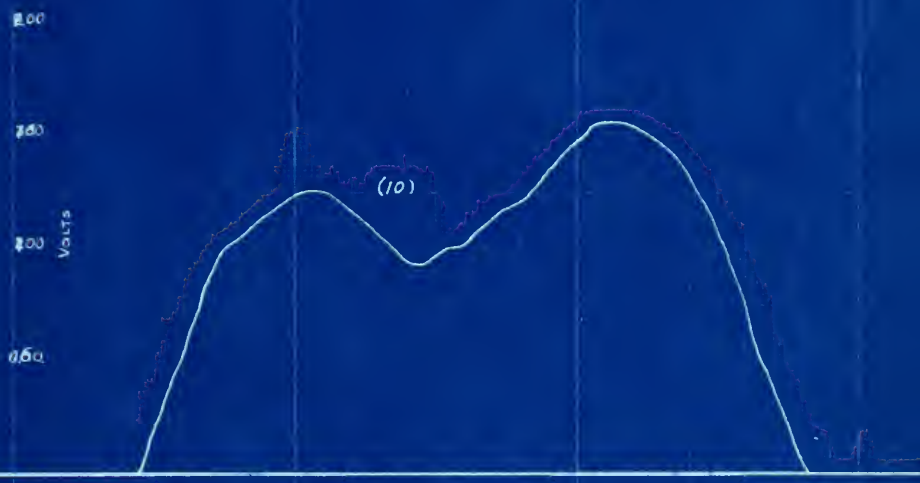
E.M.F. Test Coil #2.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

24.

Run No 3

CURVE OF INDUCED E.M.F. IN
TEST COIL NO 2
(10) EFFECTIVE E.M.F. 2.20 VOLTS
NO LOAD



EQUATION OF CURVE

$A_1 = -13.04$	$B_1 = +32.10$
$A_2 = +1.50$	$B_2 = -3.90$
$A_3 = -47.00$	$B_3 = +2.10$
$A_4 = -1.40$	$B_4 = -36.00$
$A_5 = -4.35$	$B_5 = +2.90$
$A_6 = -20.40$	$B_6 = -9.20$

A.P. Strong.

ARNOUX
INSTITUTE OF TECHNOLOGY
LIBRARY

25.

Run Number 3

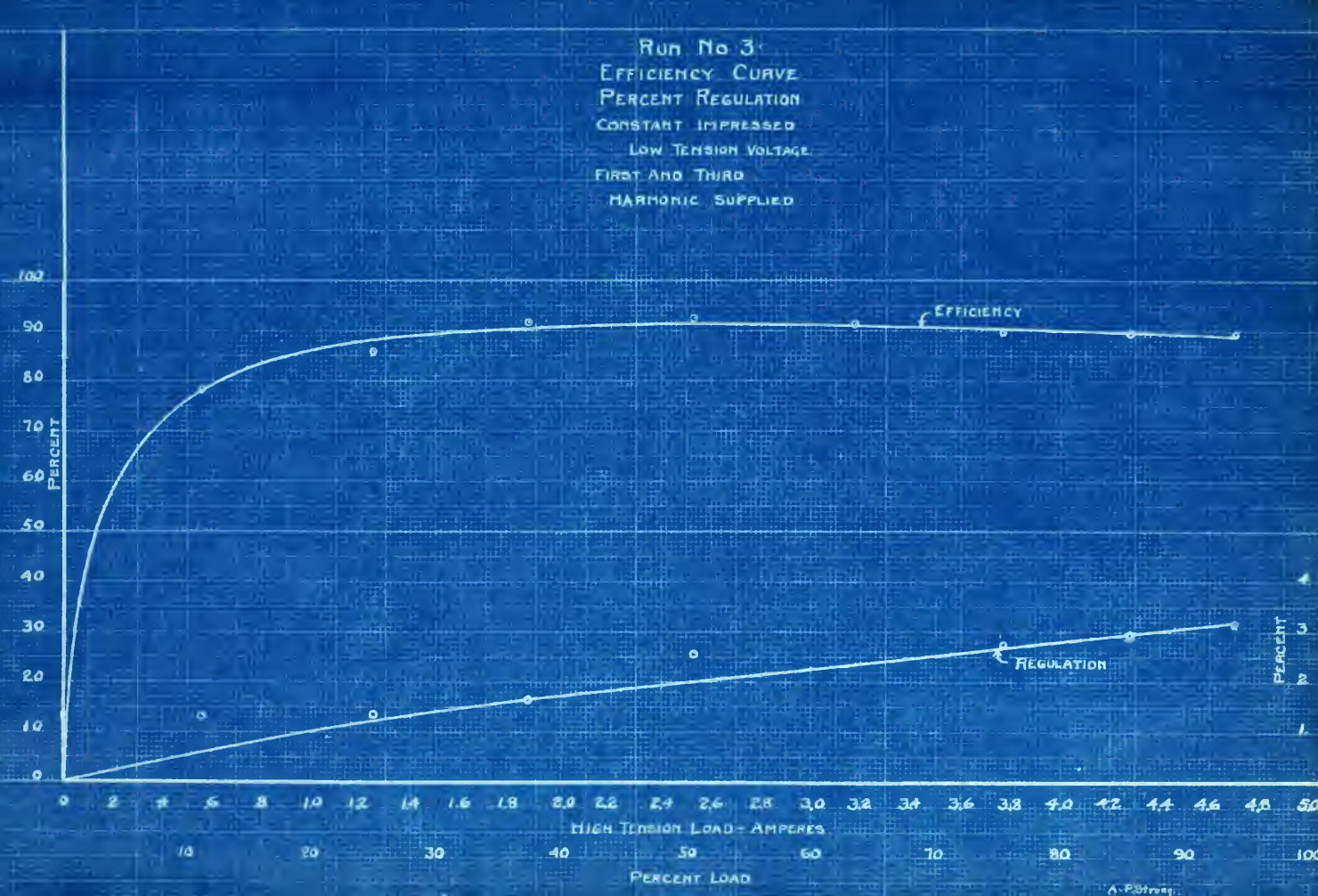
Harmonics Supplied - First - Third

Fundamental Frequency
25 Cycles Per Second

Reading Number	1	2	3	4	5	6	7	8	9
Test Coil #1									
Induced Voltage	112.0	110.7	111.2	111.0	110.0	109.9	110.0	109.9	109.6
Corrected Voltage	112.0	110.7	111.2	111.0	110.0	109.9	110.0	109.9	109.6
Number E.M.F. Curve									
Test Coil #2									
Induced Voltage	112.2	110.8	111.0	111.0	110.0	110.0	110.1	110.2	110.0
Corrected Value	112.2	110.8	111.0	111.0	110.0	110.0	110.1	110.2	110.0
Number E.M.F. Curve	10.								
Supply									
Voltage	220	220	220	220	220	220	220	220	220
Corrected Value	220	220	220	220	220	220	220	220	220
Number E.M.F. Curve	9.								
Current	1.1	4.1	7.1	10.1	13.39	16.60	19.55	22.45	24.8
Corrected Value	1.1	4.05	7.00	9.99	13.20	16.40	19.27	22.20	24.5
No. Current Curve	9_2								
Watts - Input	160	840	1620	2270	3000	3800	4680	5280	5840
Corrected Value	84	780	1580	2264	2962	3740	4580	5140	5660
Load									
Voltage	1111.0	1096.0	1093.	1096.0	1083.0	1076.0	1081.	1079.	1077.0
Corrected Value	1111.0	1096.0	1093.	1096.0	1083.0	1076.0	1081.	1079.	1077.0
Current	0	.56	1.25	1.87	2.53	3.18	3.77	4.28	4.70
Corrected Value	0	.56	1.25	1.87	2.53	3.18	3.77	4.28	4.70
Watts - Load	0	610	1380	2070	2770	3450	4125	4650	5100
Corrected Value	0	610	1360	2045	2740	3410	4075	4608	5058
Percent Efficiency	0	78.3	86.0	91.9	92.5	91.3	89.8	89.7	89.4
" Regulation	0	1.37	1.65	1.37	2.58	2.68	2.77	2.97	3.16
Hysteresis Loss	79.8								
Eddy Current Loss	4.2								

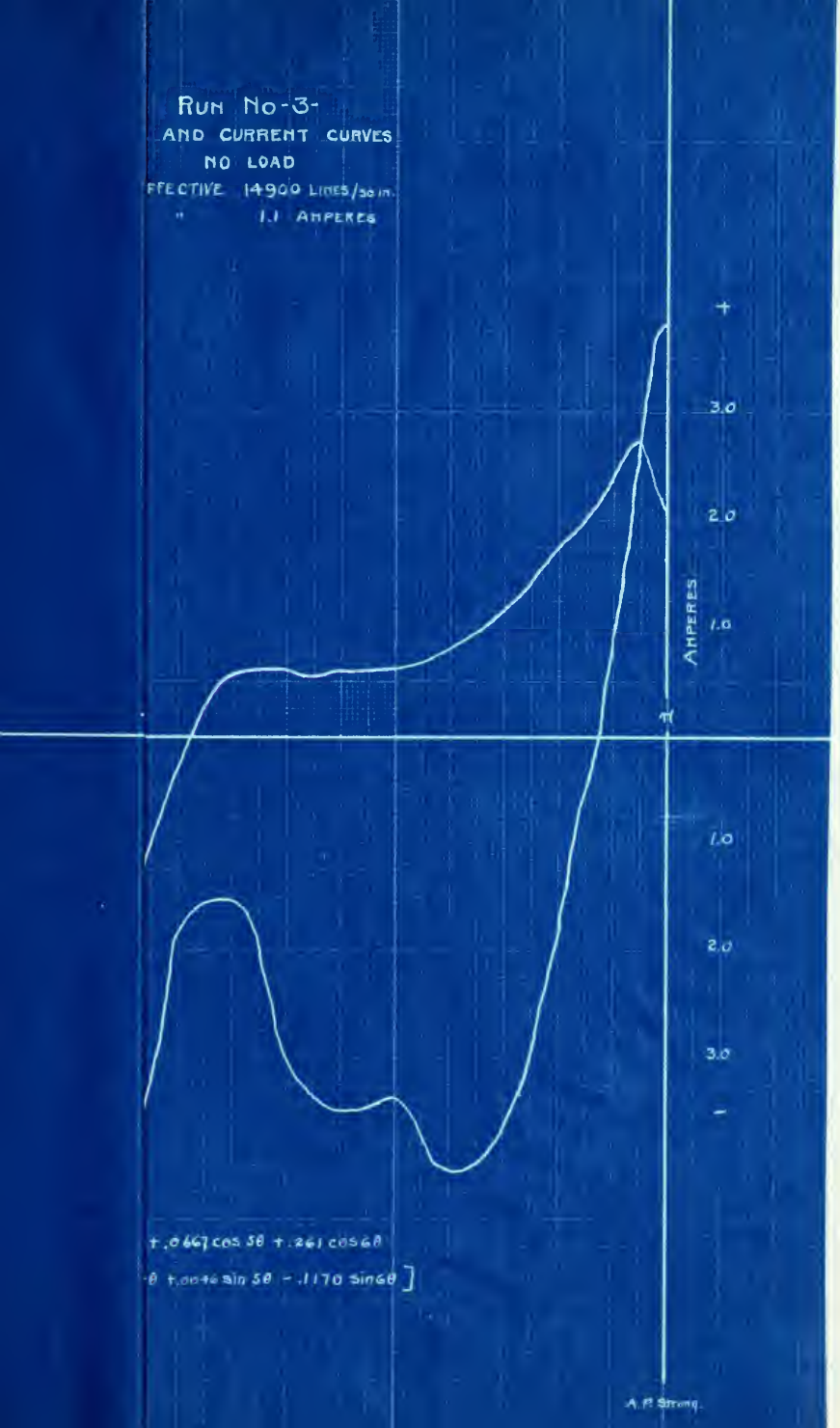
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

26.


Run No 3
Efficiency Curve
Percent Regulation
Constant Impressed
Low Tension Voltage
First And Third
Harmonic Supplied
Efficiency
Regulation
Percent
High Tension Load - Amperes
Percent Load

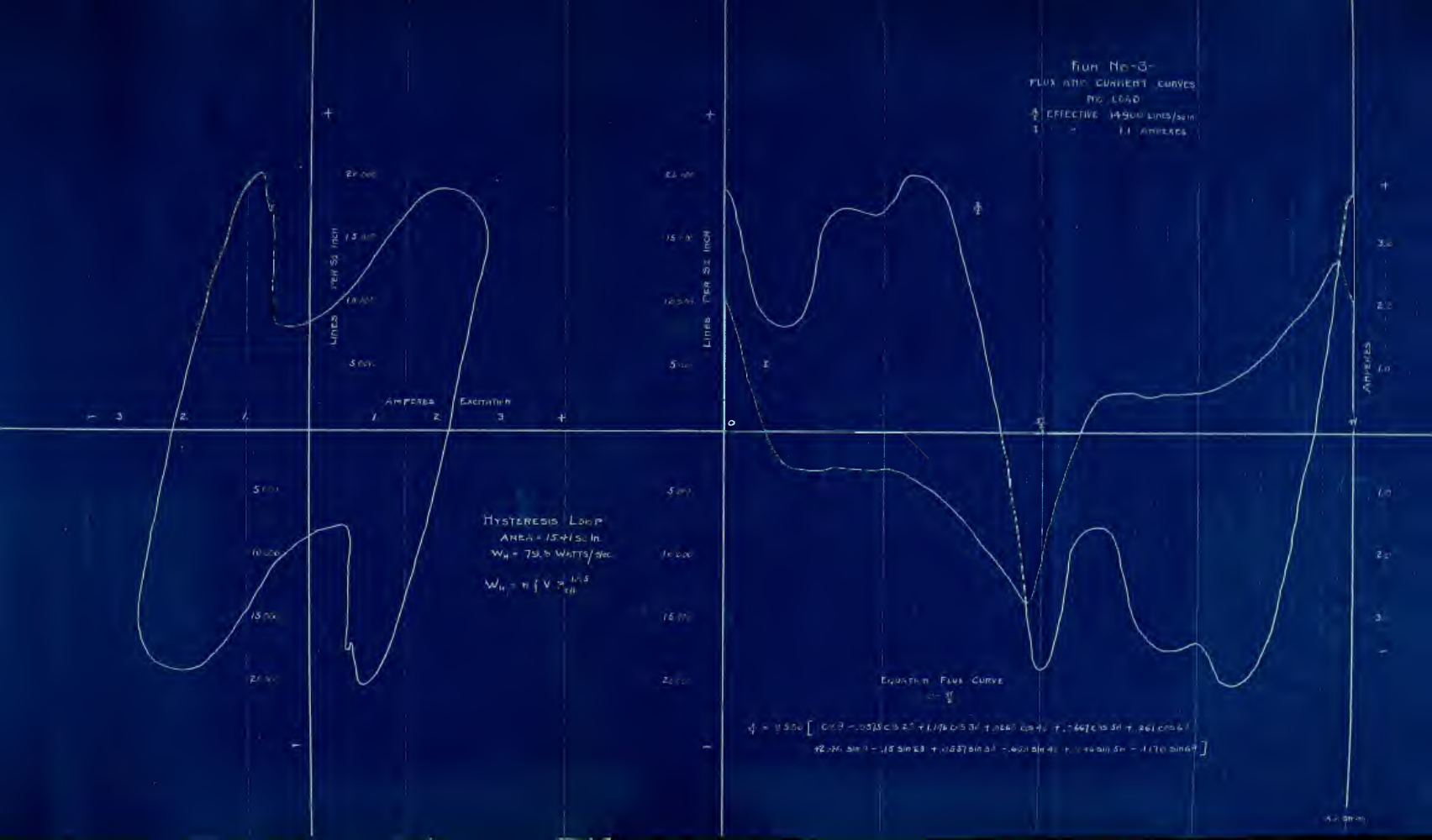
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

27.

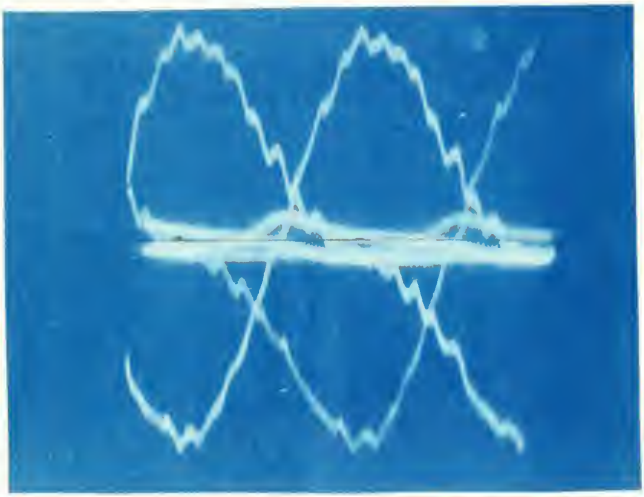

Run No-3-
AND CURRENT CURVES
NO LOAD
FFECTIVE 14900 LINES/sq in.
" 1.1 AMPERES
+
3.0
2.0
1.0
AMPERES
π
1.0
2.0
3.0
−
+.0667 cos 5θ + .261 cos 6θ
-θ +.0044 sin 5θ − .1170 sin 6θ]
A. R. Strong

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

27.


Run No-3-
Flux and Current Curves
No Load
Effective 14900 Lines/sq in
11 Amperes
Lines per sq inch
Amperes Excitation
Hysteresis Loop
Area = 15.41 sq. in.
Wh = 75.6 Watts/sec.
Excitation Flux Curve
Amperes

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY



RUN #4.

First and Second Harmonic.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

29

Run No 4-

First and Second Harmonics Supplied

Exciting E.M.F. and Current Curves

(13) Effective E.M.F. 220 Volts

(13_a) " " 0.8 Amperes

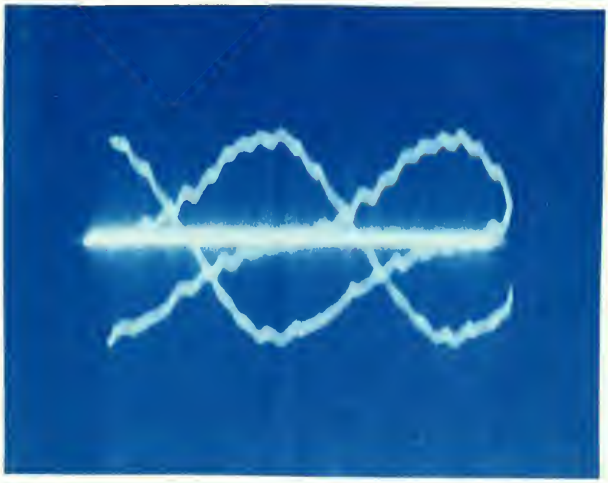
-Equation of Curves-

A	B
$A_1 = 59.70$	$A_1 = +82.50$
$A_2 = -8.03$	$A_3 = +35.90$
$A_3 = -23.90$	$A_3 = -1.21$
$A_4 = +3.28$	$A_4 = +28.17$
$A_5 = -6.83$	$A_5 = -2.92$
$A_6 = +10.17$	$A_6 = +4.28$
$B_1 = -156.1$	$B_1 = +143.20$
$B_2 = -8.34$	$B_2 = -3.58$
$B_3 = -31.40$	$B_3 = +64.20$
$B_4 = -14.61$	$B_4 = -24.34$
$B_5 = -0.33$	$B_5 = -4.37$
$B_6 = -7.06$	$B_6 = -9.45$

A.F. Strong

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

30



RUN #4.

No Load Condition Of Flux.

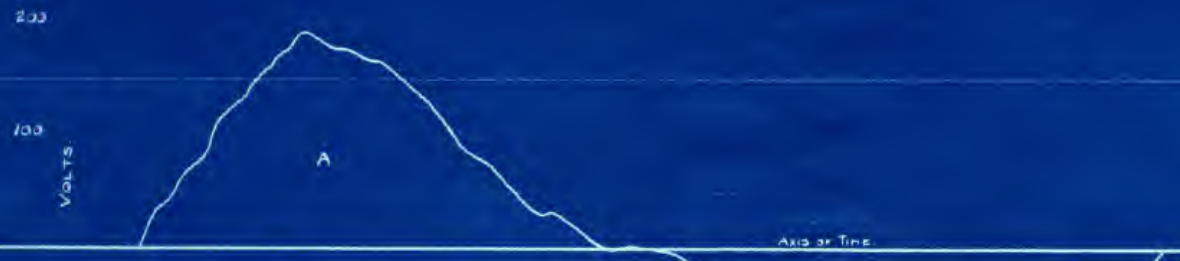
E.M.F. Test Coil #2.

ARNOUD
INSTITUTE OF TECHNOLOGY
PITTSBURGH

31

Run No 4

CURVE OF INDUCED E.M.F. IN
TEST COIL NO 2
NO LOAD
(14) EFFECTIVE E.M.F. 112. VOLTS.



EQUATION OF CURVE

A	B
$A_1 = -28.00$	$A_1 = -42.00$
$A_2 = -12.10$	$A_2 = -18.20$
$A_3 = -10.20$	$A_3 = +\ .72$
$A_4 = -\ 1.57$	$A_4 = +10.88$
$A_5 = +\ 3.41$	$A_5 = +66.90$
$A_6 = -\ 5.77$	$A_6 = +62.10$
$B_1 = +17.00$	$B_1 = -50.10$
$B_2 = -16.20$	$B_2 = +\ 1.74$
$B_3 = +15.90$	$B_3 = -32.10$
$B_4 = -\ 8.40$	$B_4 = +17.10$
$B_5 = -\ .17$	$B_5 = +\ 2.34$
$B_6 = -\ 4.09$	$B_6 = +\ 3.21$

A.P.Strong

ARNOUD
INSTITUTE OF TECHNOLOGY
LIBRARY

32

Run Number 4

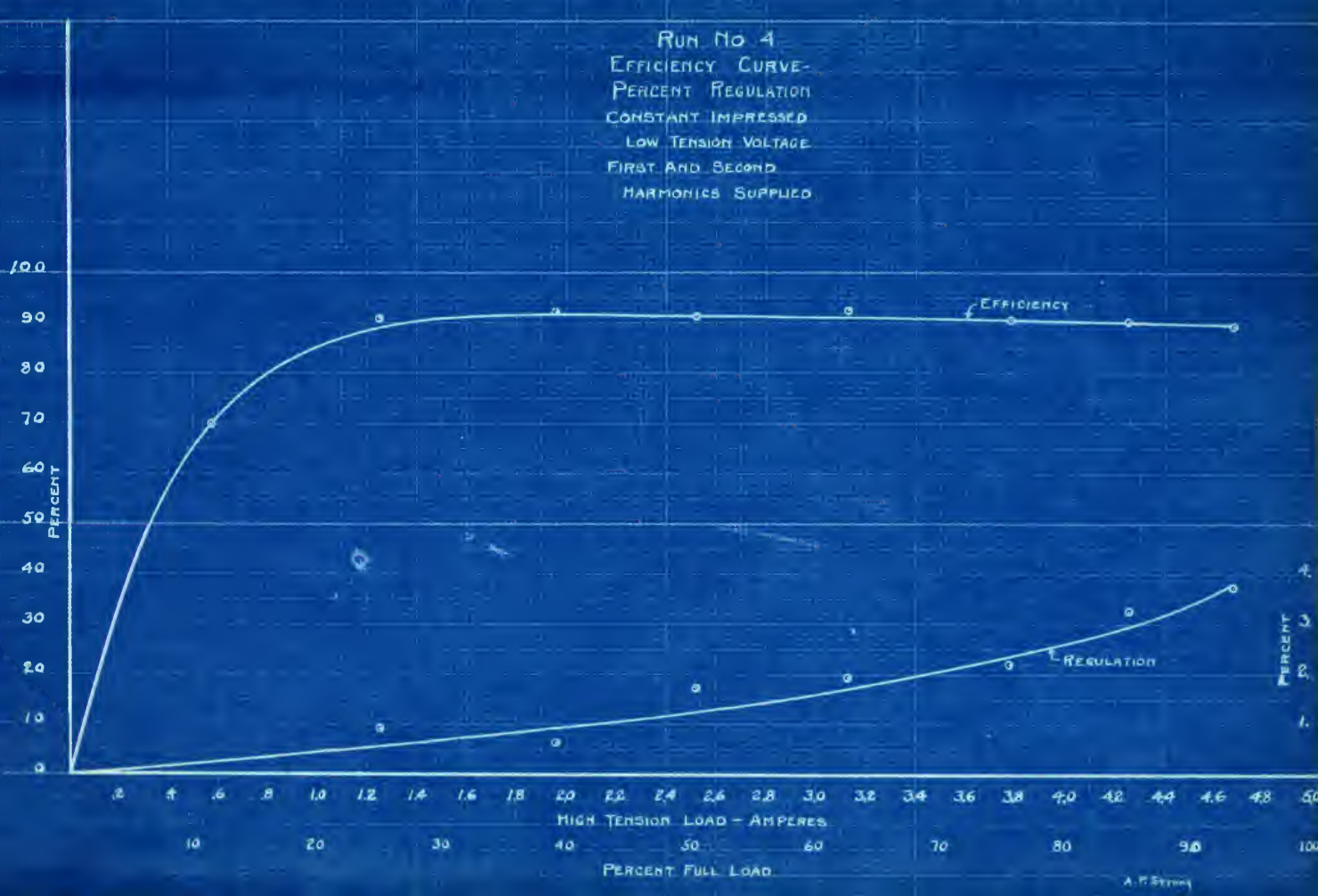
Harmonics Supplied - First-Second

Fundamental Frequency 25 Cycles Per Second

Reading Number	1	2	3	4	5	6	7	8	9
Test Coil #1									
Number E.M.F. Curve									
Induced Voltage	112.1	111.9	111.0	110.3	110.4	109.6	109.9	109.0	108.9
Corrected Value	112.1	111.9	111.0	110.3	110.4	109.6	109.9	109.0	108.9
Test Coil #2									
Induced Voltage	112.0	111.9	111.0	110.4	110.6	110.1	110.6	109.2	109.4
Corrected Value	112.0	111.9	111.0	110.4	110.6	110.1	110.6	109.2	109.4
Number E.M.F. Curve	14								
Supply									
Voltage	220	220	220	220	220	220	220	220	220
Corrected Value	220	220	220	220	220	220	220	220	220
Number E.M.F. Curve	13_1								
Current	.8	4.4	6.91	10.42	13.32	16.35	19.6	22.4	24.7
Corrected Value	.8	4.37	6.80	10.25	13.12	16.10	19.33	22.10	24.4
No. Current Curve	13_2								
Watts - Input	150	960	1540	2330	3040	3620	4620	5200	5760
Corrected Value	60.	900	1492	2280	3000	3560	4520	5060	5600
Load									
Voltage	1110.	1110.	1100.	1103.	1091.	1089.	1086.	1075.	1070
Corrected Value	1110	1110	1100	1103.	1091.	1089	1086	1075	1070
Current	0	.573	1.24	1.96	2.52	3.13	3.78	4.25	4.675
Corrected Value	0	.573	1.24	1.96	2.52	3.13	3.78	4.25	4.675
Watts - Load	0	630	1358	2080	2760	3330	4140	4550	5040
Corrected Value	0	630	1358	2100	2748	3300	4100	4620	5000
Percent Efficiency	0	70.0	91.0	92.1	91.7	92.6	90.8	90.3	89.4
" Regulation	0	0	.91	.64	1.74	1.93	2.21	3.26	3.74
Hysteresis Loss	44.6								
Eddy Current Loss	15.4								

ARNOUD
INSTITUTE OF TECHNOLOGY
LIBRARY

33


Run No 4
Efficiency Curve-
Percent Regulation
Constant Impressed
Low Tension Voltage
First And Second
Harmonics Supplied
Efficiency
Regulation
Percent
Percent
High Tension Load - Amperes
Percent Full Load
A. F. Strong

ARNOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

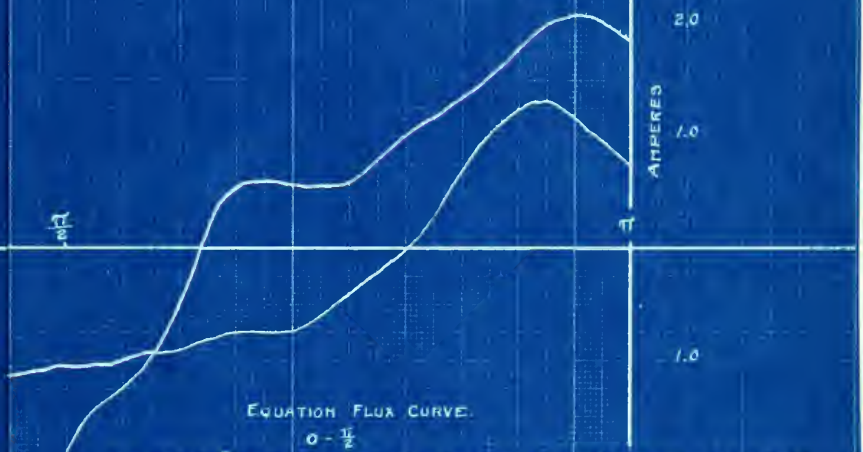
34

4

T CURVES

0 LINES/SQIN.

PERES.



EQUATION FLUX CURVE.

$0 - \frac{\pi}{2}$

$$\phi = 30450\,[\cos\theta + .216\cos 2\theta - .0057\cos 3\theta - .065\cos 4\theta - .319\cos 5\theta - .246\cos 6\theta - 1.192\sin\theta + .0207\sin 2\theta - .255\sin 3\theta + .102\sin 4\theta + .0112\sin 5\theta + .0129\sin 6\theta + 1.26]$$

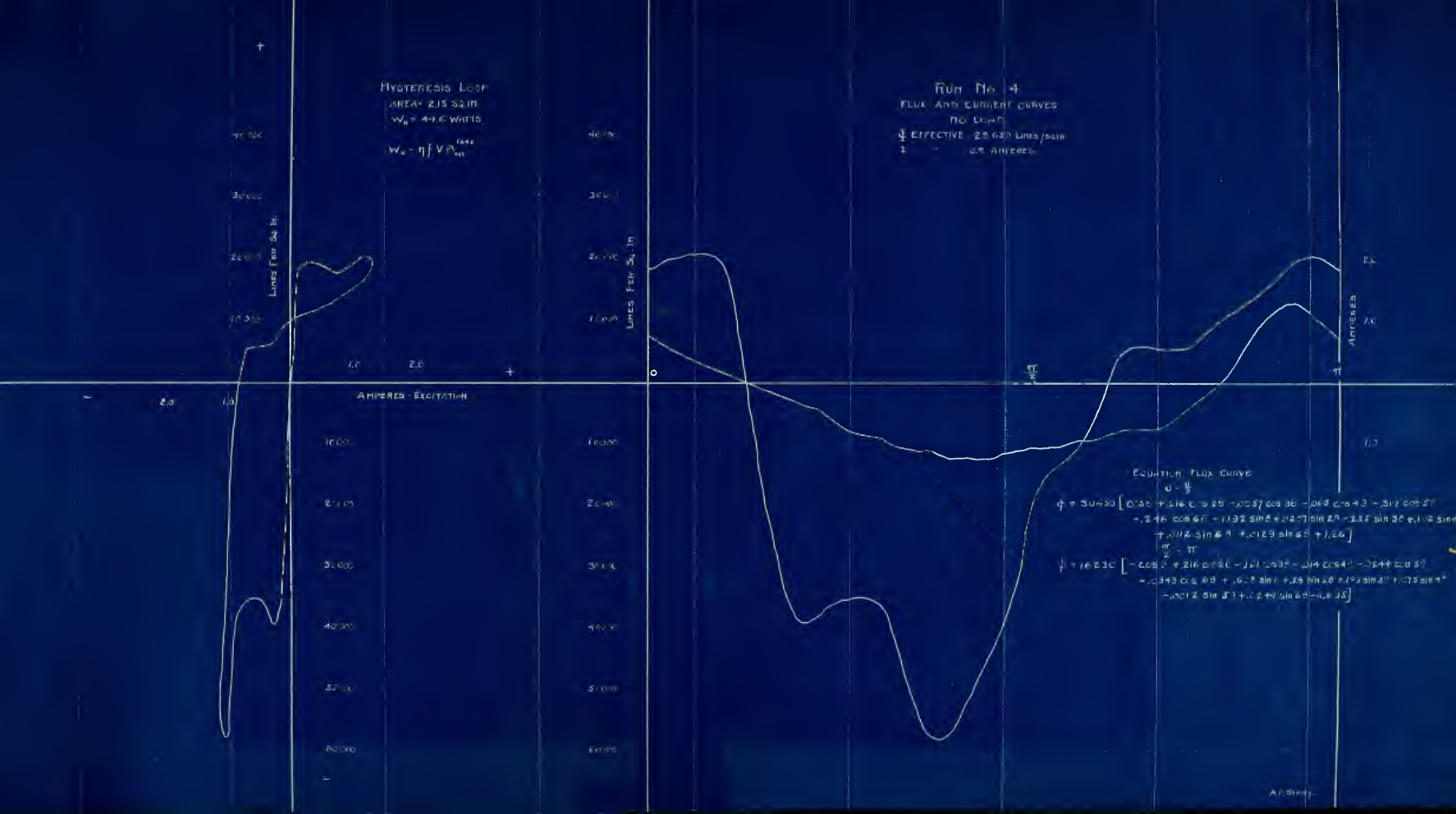
$\frac{\pi}{2} - \pi$

$$\phi = 16230\,[-\cos\theta + .216\cos 2\theta - .121\cos 3\theta - .014\cos 4\theta - .0244\cos 5\theta - .0343\cos 6\theta + .608\sin\theta + .29\sin 2\theta + .139\sin 3\theta + .075\sin 4\theta - .0012\sin 5\theta + .0244\sin 6\theta - 4.695]$$

A.F. Strong

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

34


Hysteresis Loop
Area = 2.15 sq in
W_h = 44.6 Watts
$W_h = \eta f V B_{max}^{1.6}$
Lines Per Sq In
Amperes - Excitation
Run No. 4
Flux And Current Curves
No Load
Φ Effective = 28 650 Lines/sq in
I = 0.8 Amperes
Amperes
Equation Flux Curve
0 - π/2
φ = 30450 [0.36 + .116 cos 2θ − .0057 cos 3θ − .068 cos 4θ − .317 cos 5θ
− .246 cos 6θ − .1132 sin θ + .0257 sin 2θ − .238 sin 3θ + .1[illegible] sin
+ .0112 sin 4θ + .0129 sin 5θ + 1.66]
π/2 - π
φ = 16230 [− cos θ + .216 cos 2θ − .121 cos 3θ − .014 cos 4θ − .0244 cos 5θ
− .0343 cos 6θ + .0[illegible] sin θ + .29 sin 2θ + .192 sin 3θ + .075 sin 4θ
− .0012 sin 5θ + .0242 sin 6θ − .0[illegible] 3θ]

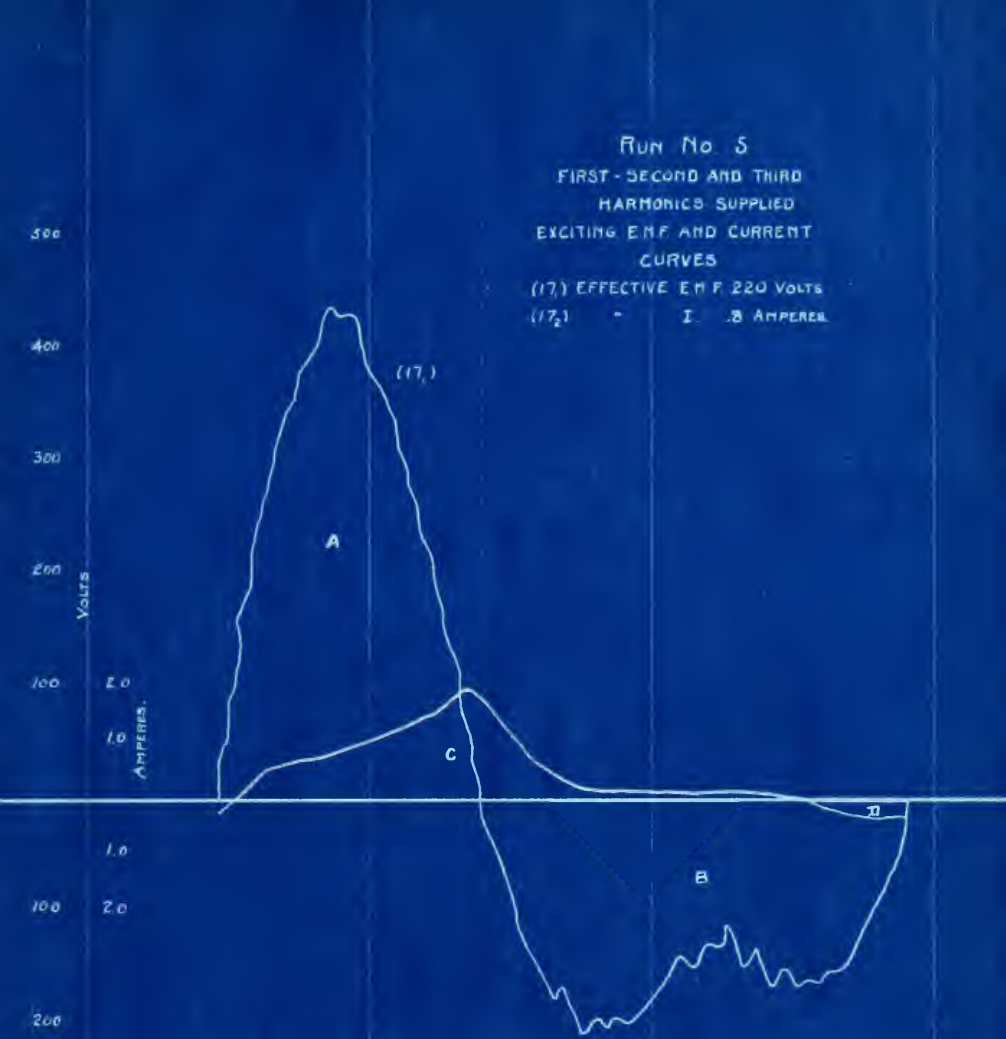
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

RUN [illegible].

First, Second and Third Harmonic.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

36.



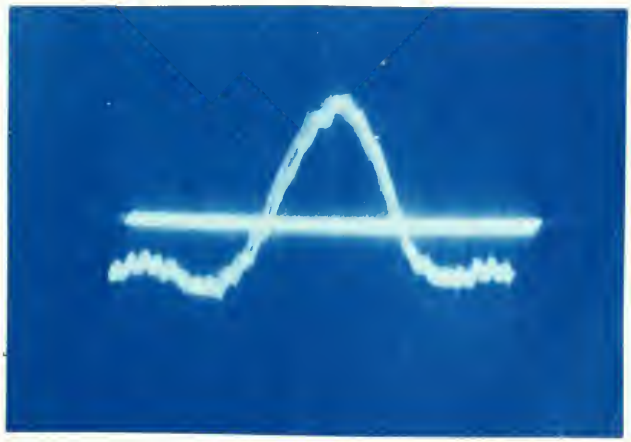
EQUATIONS OF CURVES.

E.M.F. A	E.M.F. B	CURRENT C	CURRENT D
$A_1 = -11.928$	$A_1 = +22.96$	$A_1 = -.445$	$A_1 = -.184$
$A_2 = -5.930$	$A_2 = +4.78$	$A_2 = +.277$	$A_2 = +.068$
$A_3 = -1.127$	$A_3 = +78.00$	$A_3 = -.223$	$A_3 = +.113$
$A_4 = +3.085$	$A_4 = +4.12$	$A_4 = -.147$	$A_4 = +.018$
$A_5 = +41.000$	$A_5 = +3.39$	$A_5 = +.222$	$A_5 = +.006$
$A_6 = +1.770$	$A_6 = -28.40$	$A_6 = +.108$	$A_6 = +.002$
$B_1 = +156.000$	$B_1 = +55.20$	$B_1 = +.896$	$B_1 = +.107$
$B_2 = +24.800$	$B_2 = +51.30$	$B_2 = -.053$	$B_2 = +.101$
$B_3 = -11.080$	$B_3 = +9.73$	$B_3 = -.341$	$B_3 = -.060$
$B_4 = -33.800$	$B_4 = -45.70$	$B_4 = +.184$	$B_4 = -.006$
$B_5 = -28.920$	$B_5 = -1.41$	$B_5 = +.074$	$B_5 = -.031$
$B_6 = -21.320$	$B_6 = -10.83$	$B_6 = -.134$	$B_6 = -.008$

A. P. Strong

AERONAUTICAL
INSTITUTE OF TECHNOLOGY
LIBRARY

37



RUN #5.

No Load Condition Of Flux.

L.M.F. Test Coil #9.

ARNOUD
INSTITUTE OF TECHNOLOGY
LIBRARY

38

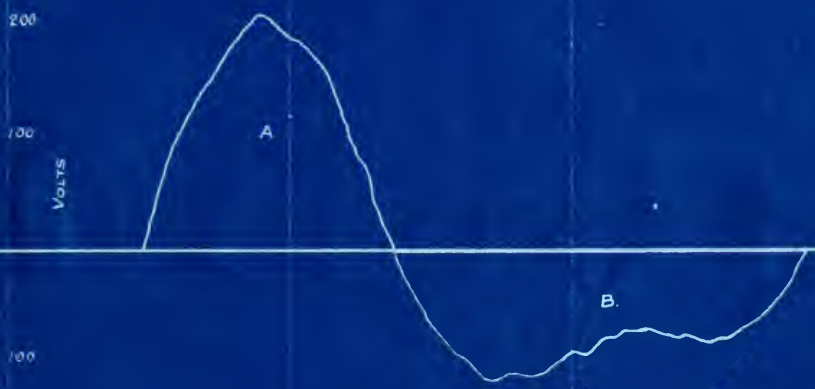
RUN No. 5

CURVE OF INDUCED E.M.F. IN

TEST COIL NO 2

NO LOAD

(18) EFFECTIVE E.M.F. 112.0 VOLTS



EQUATION OF CURVE

A	B
$A_1 = +1.520$	$A_1 = -9.50$
$A_2 = +24.34$	$A_2 = +13.82$
$A_3 = +47.20$	$A_3 = -27.90$
$A_4 = -3.70$	$A_4 = +7.61$
$A_5 = -1.37$	$A_5 = -1.28$
$A_6 = -2.01$	$A_6 = +2.03$
$B_1 = +47.60$	$B_1 = -37.80$
$B_2 = -36.62$	$B_2 = +24.10$
$B_3 = +1.36$	$B_3 = -16.20$
$B_4 = -14.20$	$B_4 = -24.00$
$B_5 = -15.17$	$B_5 = +.48$
$B_6 = -8.10$	$B_6 = -3.69$

A. F. Strong

ARNOUD
INSTITUTE OF TECHNOLOGY
LIBRARY

39.

Run Number 5

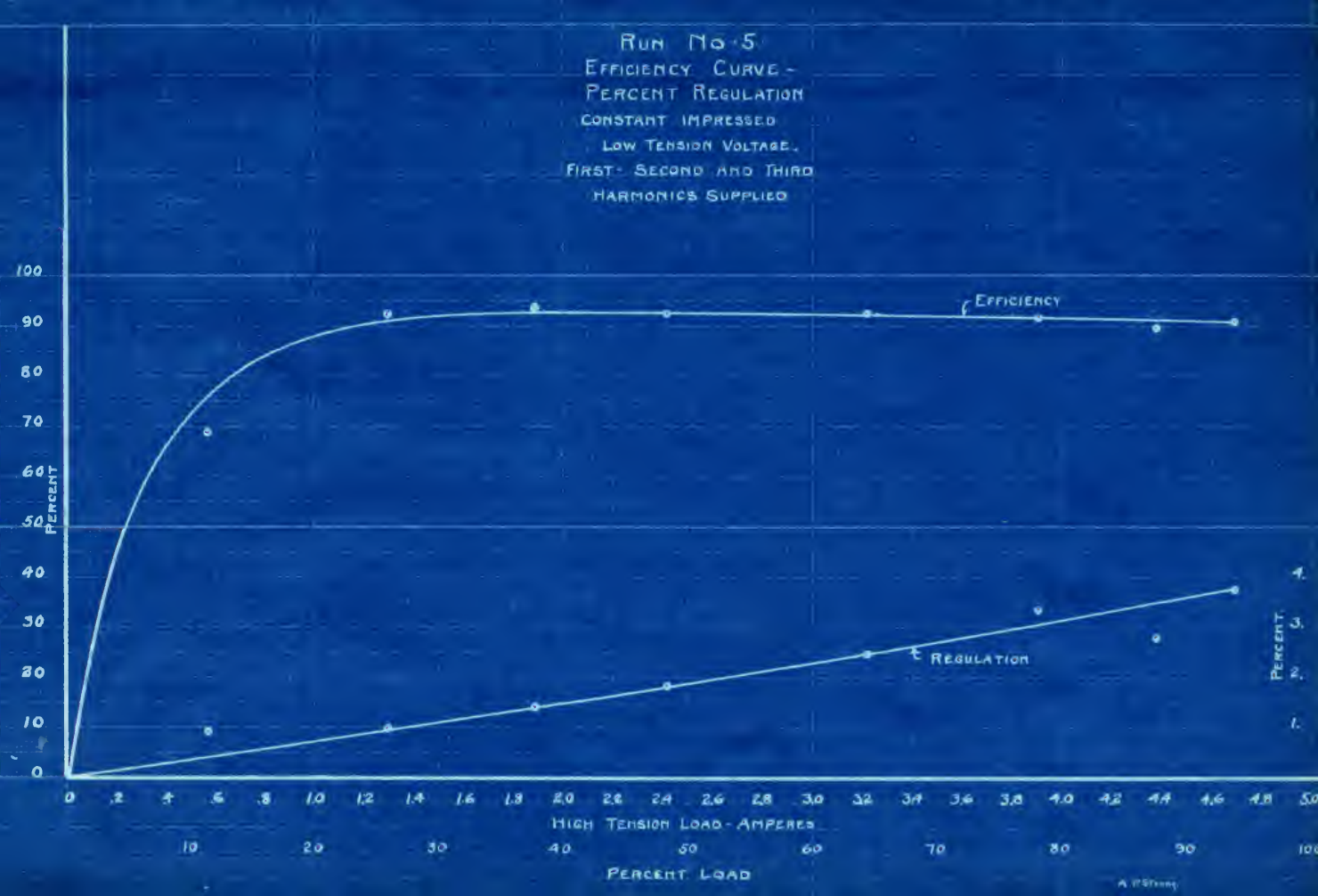
Harmonics Supplied
First - Second - Third

Fundamental Frequency
25 Cycles Per Second

Reading Number	1	2	3	4	5	6	7	8	9
Test Coil #1									
Induced Voltage	112.0	111.2	111.0	110.6	110.3	110.0	109.0	109.8	108.2
Corrected Value	112.0	111.2	111.0	110.6	110.3	110.0	109.0	109.8	108.2
Number E.M.F. Curve									
Test Coil #2									
Induced Voltage	112.0	111.2	111.0	110.6	110.3	110.0	109.3	110.0	109.2
Corrected Value	112.0	111.2	111.0	110.6	110.3	110.0	109.3	110.0	109.2
Number E.M.F. Wave	18								
Supply									
Voltage	220	220	220	220	220	220	220	220	220
Corrected Value	220	220	220	220	220	220	220	220	220
Number E.M.F. Curve	17,								
Current	0.8	4.5	7.2	10.17	12.87	16.80	20.3	23.1	24.70
Corrected Value	0.8	4.45	7.1	10.00	12.70	16.60	20.00	22.80	24.40
No Current Curve	17,								
Watts - Input	135	960	1660	2300	2880	3780	4710	5430	5680
Corrected Value	50	900	1620	2260	2840	3720	4600	5280	5520
Load									
Voltage	1110.	1100.	1098	1095.	1090.	1083.	1074.	1080.	1070.
Corrected Value	1110.	1100.	1098	1095	1090.	1083.	1074.	1080.	1070.
Current	0.0	.57	1.30	1.89	2.42	3.22	3.9	4.38	4.69
Corrected Value	0.0	.57	1.30	1.89	2.42	3.22	3.9	4.38	4.69
Watts - Load		620	1510	2140	2650	3460	4230	4770	5130
Corrected Value	0	620	1500	2120	2620	3440	4200	4728	5095
Percent Efficiency	0	69.0	92.5	93.8	92.2	92.5	91.3	89.6	90.8
" Regulation	0	.91	1.0	1.46	1.84	2.49	3.35	2.78	3.74
Hysteresis Loss	21.1								
Eddy Current Loss	28.9								

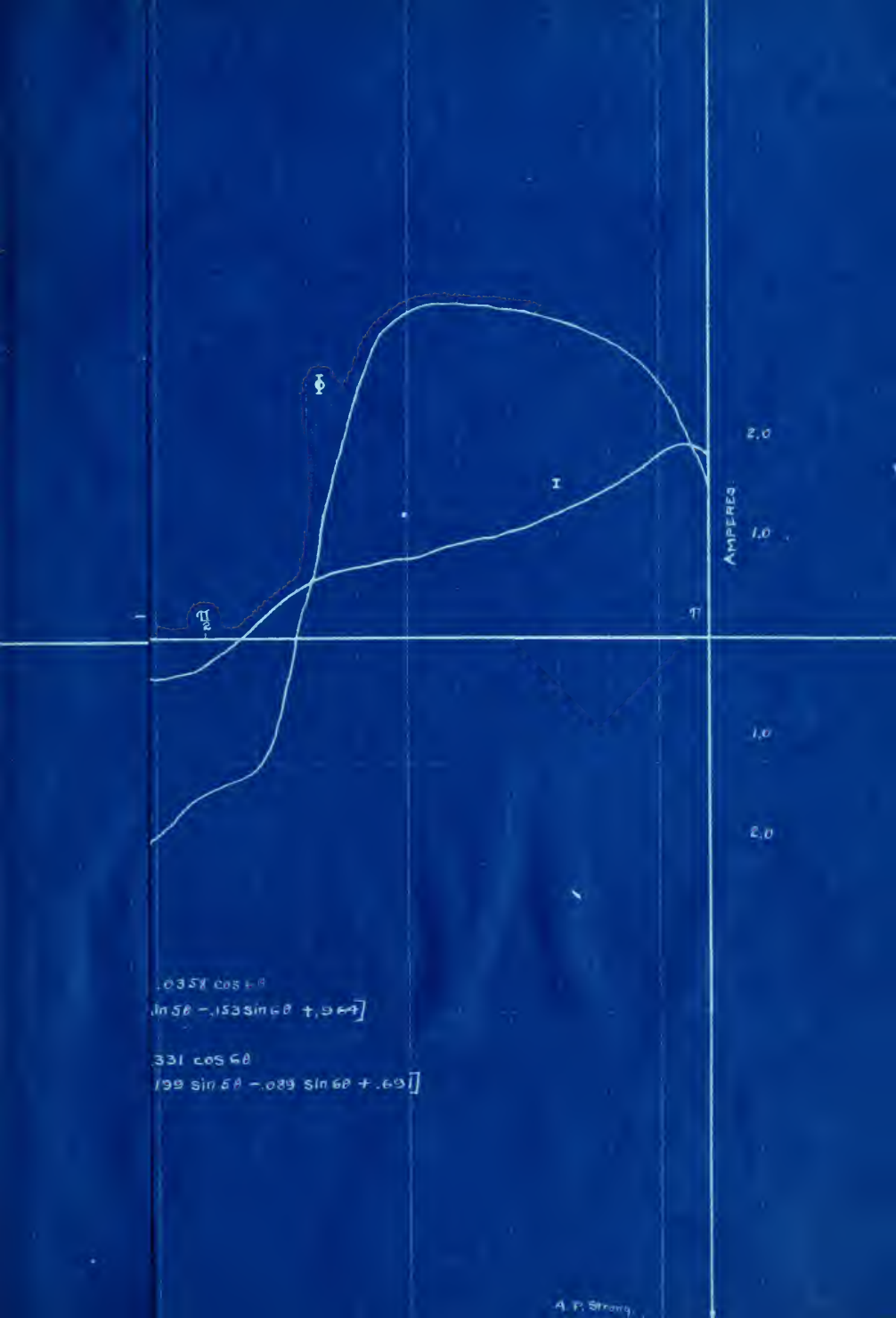
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

4c


Run No. 5
Efficiency Curve -
Percent Regulation
Constant Impressed
Low Tension Voltage.
First - Second and Third
Harmonics Supplied
Efficiency
Regulation
Percent
Percent
High Tension Load - Amperes
Percent Load

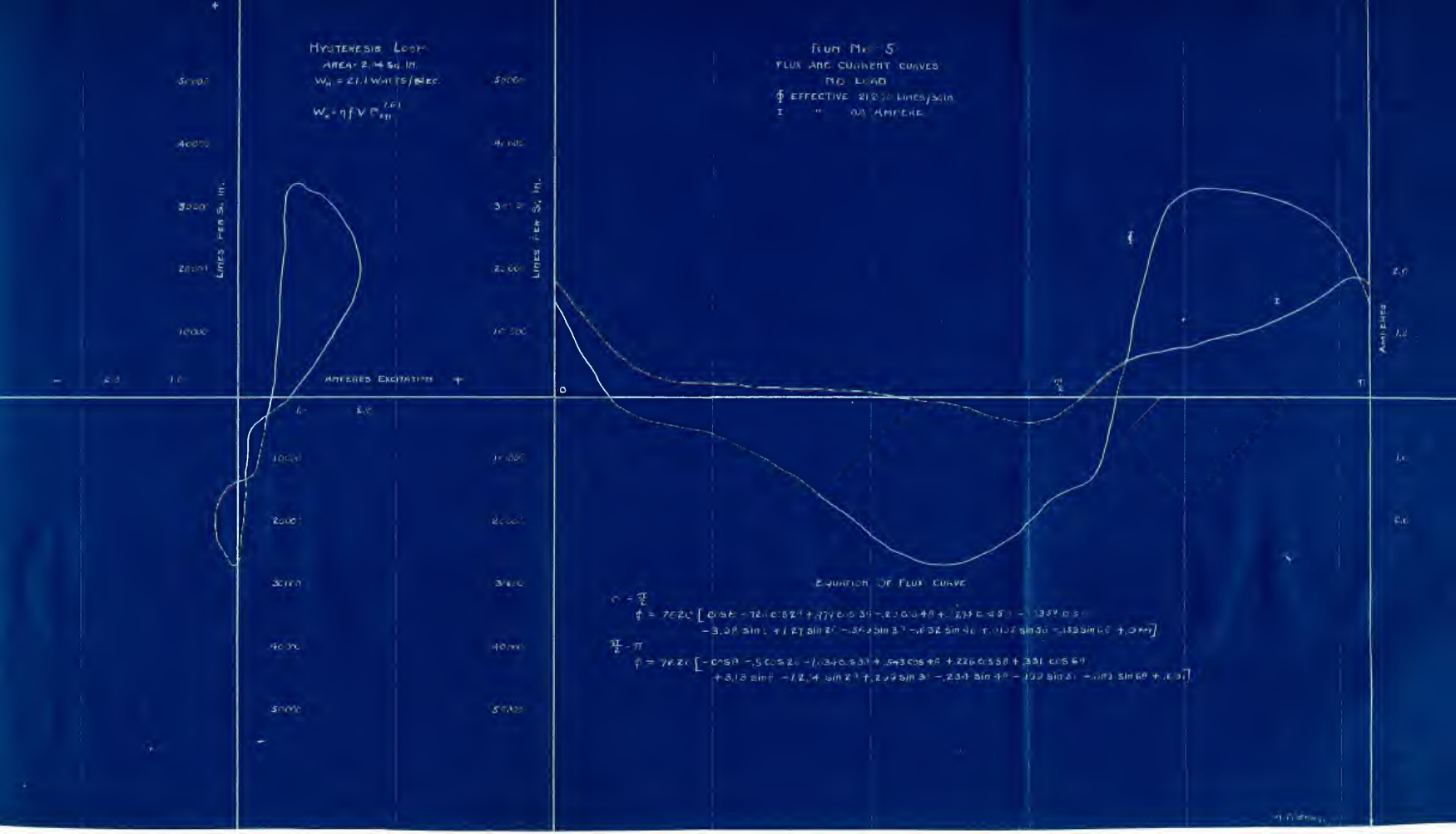
ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

41.


Φ
I
2.0
1.0
AMPERES
π
1.0
2.0
.0358 cos 6θ
in 5θ −.153 sin 6θ + .964]
331 cos 6θ
199 sin 5θ −.089 sin 6θ + .69]
A. P. Strong

ARNOUD
INSTITUTE OF TECHNOLOGY
ALLAHABAD

41.


Hysteresis Loop
Area = 2.14 sq. in.
W_h = 21.1 Watts/sec.
$W_h = \eta f V P_m^{1.61}$
Lines per Sq. In.
Amperes Excitation
Run No. 5
Flux and Current Curves
No Load
Φ Effective 212.0 Lines/sqin
I " 0.0 Amperes
Amperes
Equation of Flux Curve
$\theta = \frac{\pi}{2}$
$\Phi = 762.0\,[0.0\sin\theta - 72.1\cos 2\theta + 17.6\cos 3\theta - 2.0\cos 4\theta + 2.3\cos 5\theta - 1.33\cos 6\theta$
$- 3.0\sin\theta + 1.27\sin 2\theta - .54\sin 3\theta - .032\sin 4\theta + .102\sin 5\theta - .133\sin 6\theta + .044]$
$\theta = \pi$
$\Phi = 762.0\,[-0.0\sin\theta - .5\cos 2\theta - 1.034\cos 3\theta + .543\cos 4\theta + .226\cos 5\theta + .331\cos 6\theta$
$+ 3.13\sin\theta - 1.24\sin 2\theta + 2.44\sin 3\theta - .234\sin 4\theta - .133\sin 5\theta - .083\sin 6\theta + .031]$

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

Therefore,

$$V = \frac{194}{.277} \text{ cubic inches.}$$

$$= 700 \text{ cubic inches.}$$

Substituting the constant terms in the above formula,

$$W_h = \frac{5.86 \times 12700 \times 700 \times 25}{4 \quad 10^7} \text{ A.}$$

$$W_h = 10.37 \text{ A.}$$

DETERMINATION OF THE RELATION OF FORM FACTOR OF THE E.M.F.WAVE TO A MODIFIED FORM OF STEINMETZ CONSTANT.

$$W_h = \frac{n \; f \; V \; B^x}{10^7}$$

Where, n = Hysteretic Coefficient of Iron Used.

f = Frequency.

V = Volume of Iron cubic inches or cm. (cubic cm. used).

B = Effective value of the Flux, lines per square cm.

W_h = Hysteretic Loss.

Solving for "x",

$$x = \frac{\log W_h - C}{\log B}$$

Where, C = a constant = log (n f V).

= 2.662

Solving the above equation,

RUN #1.

$B_{eff.}$ = 4060 Lines per square cm.

W_h = 39.5 Watts.

x = 1.643

The Form Factor equals $\frac{\text{The Effective Value}}{\text{The Average Value}}$

$$F.F. = \frac{220}{190} = 1.159$$

RUN #2.

$B_{eff.}$ = 3980 Lines per square cm.

W_h = 85.5 Watts.

x = 1.740

$$F.F. = \frac{220}{163} = 1.350$$

RUN #3.

$B_{eff.}$ = 2310 Lines per square cm.

W_h = 79.8 Watts.

x = 1.850

$$F.F. = \frac{220.0}{210.6} = 1.043$$

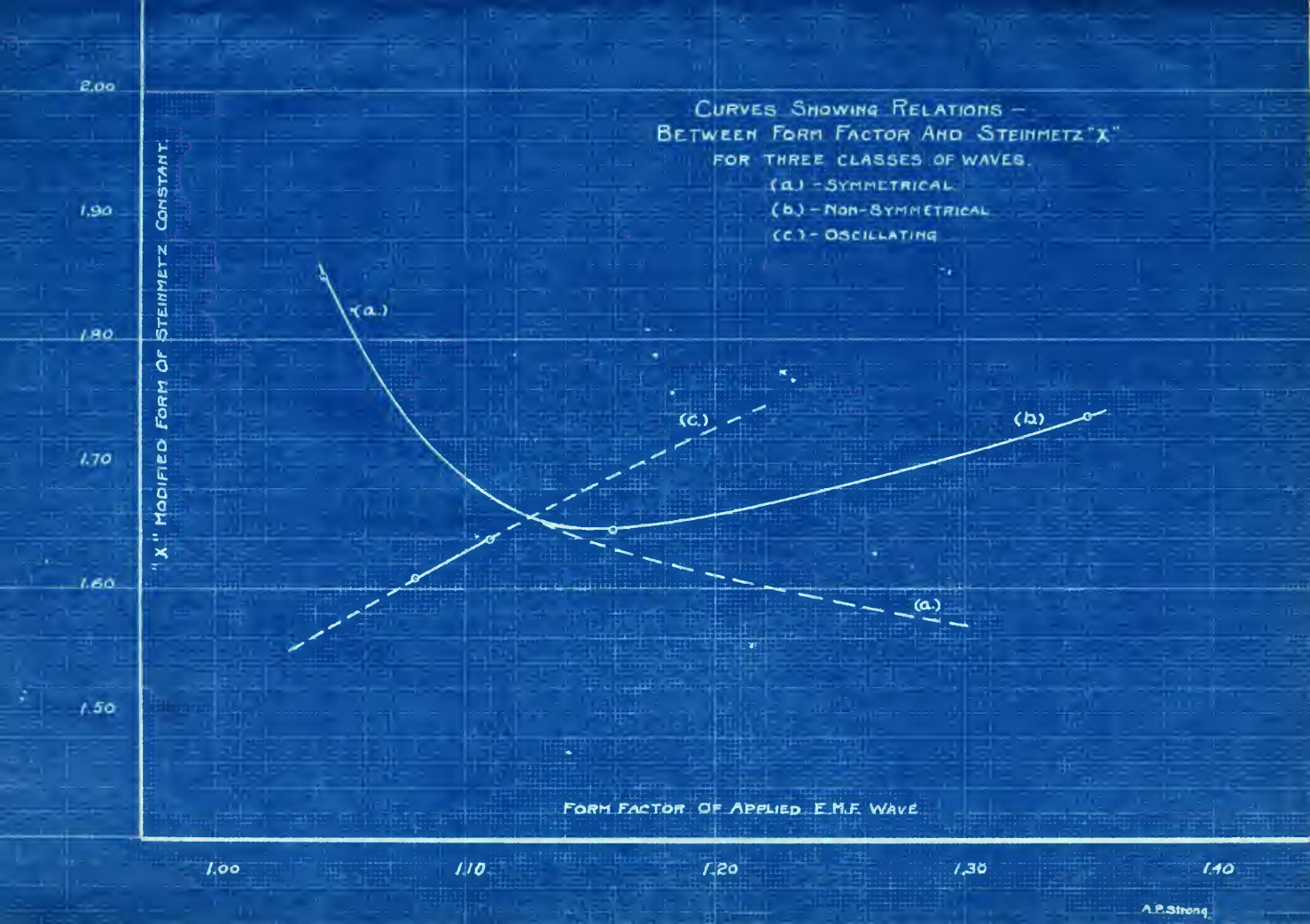
RUN #4.

$B_{eff.}$ = 4440 Lines per square cm.

W_h = 44.6 Watts.

x = 1.640

$$F.F. = \frac{220 \times 2}{218.178.8} = 1.110$$


CURVES SHOWING RELATIONS –
BETWEEN FORM FACTOR AND STEINMETZ "X"
FOR THREE CLASSES OF WAVES.
(a.) – SYMMETRICAL
(b.) – NON-SYMMETRICAL
(c.) – OSCILLATING
"X" MODIFIED FORM OF STEINMETZ CONSTANT.
2.00
1.90
1.80
1.70
1.60
1.50
(a.)
(c.)
(b.)
(a.)
FORM FACTOR OF APPLIED E.M.F. WAVE
1.00
1.10
1.20
1.30
1.40
A.P.Strong

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

43

RUN #5.

$B_{eff.}$ = 3290 Lines per square cm.

W_h = 21.1 Watts.

x = 1.610

$$F.F. = \frac{220 \times 2}{238.2 \quad 139.0} = 1.090$$

DISCUSSION OF EXPERIMENTAL RESULTS.

A wave of applied E.M.F. of large Form Factor may either produce a low or a high iron loss. In Run #1 the Form Factor is larger than that for a sine wave (Form Factor of a sine wave = 1.1105) and a low iron loss results. In Run #2 a still larger form factor is obtained,yet a high iron loss results. A large form factor would naturally,reasoning from the result of Run #1,mean a still lower iron loss. We have as it were considered only a vertical ratio in dealing with the form factor. The wave of applied E.M.F. in RUN #1 is nearly symmetrical with a vertical line drawn through the point on the X-axis equal to $\frac{\pi}{4}$. In Run #2 the wave of applied E.M.F. is not symmetrical with a line drawn through the point on the X-axis equal to $\frac{\pi}{4}$. In Run #3 the wave is a flat one nearly symmetrical about a vertical line drawn through $\frac{\pi}{4}$. So we may expect it to follow the way of #1. A form factor less than a sine wave is found,so a large iron loss is expected. The results agree.

Run #4 has an E.M.F. wave shape kindred to the

oscillating wave. That is: its positive and negative lobes are not of the same value as regards form factor frequency, or effective value.

It would seem however, that on the whole that the form of wave shown in Run #5 although of small iron loss, does not present any advantage, the large pulsation of effective value, from a maximum positive to a minimum negative, causing a decided flicker of the lights which is still further augmented by the periodic change of frequency. As for power use this periodic change of frequency would cause the motors on the line to hunt. This is emphasized by the pounding effect of the small synchronous motor used to drive the oscillograph shutter.

CONCLUSIONS.

For waves that are symmetrical about a line drawn through the point on the X-axis $\frac{\pi}{4}$, the iron loss varies inversely with the form factor of the wave. For waves that are badly non-symmetrical with a line drawn through the point $\frac{\pi}{4}$, the iron loss varies directly with the form factor of the applied wave. In defining a wave by means of the form factor, when referring to iron loss, it is therefore necessary to say whether it is symmetrical about a vertical axis through point $\frac{\pi}{4}$, or not and the degree of non-symmetricallity.

In referring to the oscillatory class other being

things being constant, the iron loss varies inversely with the constant A_0 in the general equation,

$$e = A_0 + A_1 \sin \theta + A_2 \sin 2\theta + A_3 \sin 3\theta \text{ ----} + A_n \sin n\theta$$
$$+ B_1 \cos \theta + B_2 \cos 2\theta + B_3 \cos 3\theta \text{ -----} + B_n \cos n\theta.,$$

for oscillatory periodic waves.